CLOSE, CLOSER, AND EVEN CLOSER: INTRODUCTION OF THE

DIGITAL MICROSCOPE INTO ELEMENTARY (K–5)

ENRICHMENT AND ART CLASSROOMS

Except where reference is made to the work of others, the work described in this dissertation is my own or was done in collaboration with my advisory committee. This dissertation does not include proprietary or classified information.

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CLOSE, CLOSER, AND EVEN CLOSER: INTRODUCTION OF THE DIGITAL MICROSCOPE INTO ELEMENTARY (K–5) ENRICHMENT AND ART CLASSROOMS

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DIGITAL MICROSCOPE INTO ELEMENTARY (K–5)

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VITA

The author, Lucille W. Beardsley, graduated from Southern Connecticut State College with a Bachelor of Science degree in Elementary Education, with a major concentration in mathematics, and from Fairfield University in Connecticut with a Master of Arts degree in Elementary Education. She holds certifications as an Elementary Educator (pre-K through grade 8) and an Earth Science Educator (grades 6–12).

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DISSERTATION ABSTRACT

CLOSE, CLOSER, AND EVEN CLOSER: INTRODUCTION OF THE DIGITAL MICROSCOPE INTO ELEMENTARY (K-5) ENRICHMENT AND ART CLASSROOMS

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Doctor of Philosophy, December 19, 2008
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This study examines the effect of introducing digital microscopy into two elementary classrooms: Teacher E's enrichment classes and Teacher A's art classes. Data were obtained during 2004 by conducting preliminary interviews, interviews after the first lesson, and post-interviews with the teachers. This was supplemented by making classroom observations as a participant observer during 2004 and 2005. In 2006, similar interview data were obtained on two occasions (interviews after digital microscope lessons and post-interviews) and there were supplementary classroom observations.

Participating teacher interviews were transcribed and then coded for semantic domain analysis. Semantic domain analysis revealed that coded comments fell into nine main categories: (1) *characteristic*; (2) *comparison*; (3) *computer*; (4) *connection*; (5) *knowing*; (6) *object*; (7) *seeing*; (8) *students*; and (9) *teacher*.

The results of this study revealed that the introduction of the digital microscope into elementary classrooms had many similar effects during both enrichment and art lessons. Among the similar effects for both teachers were the following: (1) they practiced authentic inquiry during their respective lessons for enrichment (science and non-science) and art classes; (2) they began by directing the inquiry lessons, but became participants with their respective students in digital microscope lessons, and these lessons became more student-driven, went in unexpected directions, and yielded unexpected results; (3) they noted that students expressed a strong sense of ownership of their findings, digital images, and videos and that the students wanted to share those things with classmates and at home; (4) they felt that the digital microscope helped them find new ways to meet educational standards and that the lessons with digital microscopy had strong interdisciplinary potential; (5) they wanted to share digital microscopy with other teachers and spoke about wanting to make digital microscopy web-pages; and (6) they reported similar student interactions during digital microscope lessons, including wanting: to work as a group, to look at what they wanted to see, to have more time for lessons, engaging in discourse (including utterances, gestures, and body language) about their findings, and to see what others were finding all at the same time.

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I. NATURE OF STUDY

Introduction

This study examined the effect upon two teachers when an inexpensive, yet versatile and visually engaging new technology, digital microscopy, was introduced into their elementary school classrooms. This study took place in a town of about 50,000 residents in the southeastern United States, and included a kindergarten through grade five (K–5) elementary art teacher and a K–5 elementary enrichment teacher.

The study used a qualitative, phenomenological approach (Agar, 1980; Spradley, 1980; Guba & Lincoln, 1989; Merriam, 1998; Upitis et al., 1997; van Manen, 1990) in analyzing and presenting findings. This approach is explained in detail in Methodology, Chapter III. The researcher interviewed the two participating teachers and, further, the researcher acted as a participant observer in the two participating teachers' classrooms. This study focuses on experiences of the two participant teachers as they engaged in new learning and teaching experiences using digital microscopy in their classrooms.

In January 2004, a one-year grant was given to a professor (the principal investigator), who was a petrologist and microscopist at a university in the same community as the elementary school. The grant created a type of collaboration or partnership between the principal investigator and the participating teachers. The grant provided digital microscope equipment, related laptop computers, and associated training for classroom use by the two participating teachers and other teachers at the school. The researcher participated in this grant project with the principal investigator, observed as the digital microscope was introduced into the two classrooms noted above, and helped conduct a teacher workshop and national conference Share-a-Thon related to this project on digital microscopy.

Over the period of this study (2004–2006), the teachers worked with the digital microscopes during various kinds of lessons in their respective classes. The researcher’s interviews of these teacher and the researcher’s classroom observations of these teachers during this project formed the data base for this report.

Significance

The purpose of this report was to study the introduction of digital microscopy technology into the previously mentioned elementary classrooms and the resulting changes in what participating teachers did and said during the period 2004–2006. Additional information on the purpose of this study could be found in Chapter III, Methods.

The significance of this research was that it showed the many different and specific effects that could arise from the introduction of a rather simple, new technology into elementary school classrooms. This study also showed the many similarities in nature and evolution of digital microscope lessons within both science and non-science lessons conducted by two teachers in different curriculum areas. For the teachers, this was an opportunity to learn about new digital microscope technology and discover ways of engaging students with this technology. Both teachers were engaged initially in a scientist-teacher partnership, which was propelled by a grant that brought digital microscopes and laptop computers to the elementary school. During this study, students in both the participating teachers' classrooms conducted some authentic inquiry on their own, explored the microscopic world of selected specimens, and captured them as digital images and video files as part of class activities. The researcher wanted to examine the effects of this new technology upon these elementary classrooms by working with two teachers to study this issue.

Research Questions

The main research question was: How does the introduction of the digital microscope into elementary enrichment and art classrooms affect what teachers say and do?

Related to the main research question, the other research questions are as follows:

1. How does the introduction of the digital microscope into classrooms affect the way that the participant teachers view science and technology?

2. How does the introduction of the digital microscope into classrooms affect the way that the participant teachers teach their classes that use microscopy?

3. How does the introduction of the digital microscope into classrooms affect the way that the participant teachers view student learning using microscopy?

II. REVIEW OF LITERATURE

This literature review commences with a discussion of collaboration, partnership, and authentic science because the grant project that was the original impetus for this study was rooted in these concepts. Next, this review covers pedagogy in the classroom, including communication, how people learn, constructivism, learning environments, student behavior, and teacher change. Following the discussions on topics related to pedagogy, there is a section on student conceptions about scientists and science, the natural world, and art and science. This chapter ends with a discussion of microscopy and digital microscopy, including the history of microscopy, evolution of microscopes, nature of microscopes, and digital microscopy.

Collaboration, Partnership, and Authentic Science

Collaboration

As noted by Cummings (2004), there was considerable variation in the way that collaborative arrangements between scientists and schools were defined. Cummings (2004) referred to a continuum from coordination, to cooperation, and ultimately to collaboration. Coordination involved short-term arrangements that did not require changes in the participating school's policies, procedures, or funding. Cooperation may be a slightly longer term arrangement that might require slight changes at the school.

Collaboration was typically a longer term venture requiring adaptation and change in policy, procedure, and funding. Further, collaboration had a goal that could not be achieved without the arrangement between scientist(s) and a school or schools. Cummings (2004) pointed out that consultation was an important part of collaboration and that collaboration almost always occurred in the context of relationship building. According to Cummings, collaboration was defined as "a cumulative process involving a range of often more limited activities and approaches that, over time, build the confidence and trust that are essential to interdependence" (Cummings, 2004, p. 6). Gosselin et al. (2003) used the term collaboration in order to emphasize that there was a "working relationship [of professionals] … in order to accomplish a goal that they share" (p. 118). Gosselin et al. (2003) noted that the characteristics of effective collaboration were: voluntary participation; a parity basis; shared goals; shared responsibility; shared accountability; shared resources; and emergent ideas.

Partnership

A type of collaboration that had been the subject of much study in recent years is the partnership. The partnership might be composed of student-scientist (Barab & Hay, 2001; Bradsher & Hagan, 1995; Lawless & Rock, 1998; Rock & Lauten, 1996; Spencer et al., 1998; Tinker, 1997), teacher-scientist (Carlson & Simons, 1993; Gosselin et al., 2003; Harnik & Ross, 2003), teacher-student (Cornell, 1998; Liem, 1987), or student-scientist-teacher relationships (Gibson, 1987; Ledley et al., 2003; Rahm et al., 2003; Wormstead et al., 2002). A partnership was defined by Marek (2002) as "a symbiosis where each entity gains greatly through collaborations in teaching, research, and service" (p. 1). Marek pointed out that many of the science teachers involved were participants in “joint grant projects, collaborative research studies and presentations, youth academies and in-service institutes, adjunct teaching in science education at [a] university, and/or graduate studies in science education at [a] university” (Marek, 2002, p. 1). Many current partnerships were closely aligned with National Science Education Standards (Harnik & Ross, 2003; TERC & The Concord Consortium, 1996). Whereas most partnerships involved face-to-face work (e.g., Hall-Wallace & Regens, 2003a, 2003b), others were largely online partnerships (e.g., O’Neill, 2001; O’Neill & Abeygunawardena, 2000; Tinker, 1996).

Authentic Science

Authentic science was a term commonly associated with collaboration and partnerships in science education (Bencze & Hodson, 1999; Gaskell, 1992). Rahm et al. (2003) defined authentic science as an emergent property within partnerships that was brought about directly by the interactions among students, teachers, and scientists within partnerships. Authentic science was therefore an expected outcome of a partnership, and Rahm et al. (2003) went on to say that authentic science learning environments were created by effective partnerships in science education. They advocated authentic science as a way of engaging students and teachers that went beyond static science classroom learning. In their view, authentic science was a way of avoiding standard science classroom practices that would always be different from what real scientists did. They also pointed out that, like real science, the outcome of authentic science might not be entirely predictable. This was consistent with their notion that authentic science emerged rather than having been outlined beforehand, like a textbook would have been. This might be especially true when the partnership involved real world problems (e.g., Bouillion & Gomez, 2001). Many authors (e.g., Duchovany & Joyce, 2000; Jarett & Burnley, 2003), had connected authentic science and scientific literacy among participating students and their teachers.

Impetus for Collaboration, Partnership, and Authentic Science

One of the most widely cited reports concerning the national problem of improving scientific literacy was the 1989 *Science for All Americans*, an extensive report of Project 2061, an entity of the American Association for the Advancement of Science (AAAS;1989). The Project 2061 report viewed the traditional treatment of science as a collection of abstract, unrelated facts as a poor model for science education and proposed a thematic approach to science education and preparation of students to understand the natural world (Metzger & Geary, 1992). Four years later, the AAAS issued its *Benchmarks for Scientific Literacy*, which said that students should be able to "frame the question, design the approach, estimate the time and costs involved, calibrate instruments, conduct trial runs, write a report, and finally respond to criticism" (AAAS, 1993, p. 9). Not surprisingly, a number of different methods for addressing this long-standing defect in public science education were put forward after these reports, including many proposals that resurrected an old notion that participation in science helped students understand the scientific method (Lane, 1996a).

One of the earlier, best-known, and largest efforts at collaboration and partnership in science education was GLOBE, Global Learning and Observation to Benefit the Environment, which was first proposed in 1992 by Vice President Al Gore in his book *Earth in the Balance* (Gore, 1992; discussed by Finarelli, 1998). GLOBE was an international science education program, which at its peak involved about 10,000 schools in 96 countries, that still serves as a model of what could be done with a very large program of this sort (Butler & Coppola, 1996; ; Butler & MacGregor, 2003Finarelli, 1998; Wormstead et al., 2002).

In 1996, a national conference on “Student and Scientist Partnerships,” which was funded by the National Science Foundation, was held in Washington, D.C. The Conference report of this meeting (TERC & The Concord Consortium, 1996) is still a widely cited document for the practice and funding of such partnership efforts.

From 1996 to date, many large-scale, funded and unfunded collaborations and partnerships have been developed that involved student-scientist, teacher-scientist, and/or student-scientist-teacher configurations. Thirteen of the larger partnership programs were briefly reviewed by Hall-Wallace and Regens (2003a; 2003b). Other partnership programs of note, which were published recently include: the National Teacher Network (Hoff & Leiker, 1992); the Bay Area Earth Science Institute (Metzger & Geary, 1992); Project Catalyst (Carlson and Simons, 1993); the Kid’s Network (Bradsher & Hagan, 1995); the Kansas Collaborative Research Network (KanCRN; Case, 1996); the Global Rivers Environmental Education Network (GREEN; Wheeler, 1996); the Hands On Universe (HOU; Pennypacker, 1996); the Forest Watch program (Rock & Lauten, 1996); the STELLAR program (Gonzales, 1998); the Boreal Forest Watch (BFW; Spencer et al., 1998); the Tardigrade Biodiversity Project (Case & Miller, 1999); the Mars Pathfinder Field Trips (Edgett, 2000); the Traveling Science Boxes Program (Cannon, 2000); the Science Apprenticeship Camp (Barab & Hay, 2001); the Chicago River Project (Bouillion & Gomez, 2001); the Collaboration to Advance Teaching Technology (CATTS; Hall-Wallace & Regens, 2003a; 2003b); the N-STEP in-service teacher project

(Buck, 2003); the Moonsnail Project (Hansen et al., 2003); the Mastodon Matrix Project (Ross et al., 2003); the Teachers as Leaders Research-Based Science Education (TLRBSE) workshops (Rapp, 2003); the Earth System Scientist Network (ESSN; Ledley et al., 2003); and the Reaching Out to Communities and Kids with Science programs (ROCKS; White et al., 2003). Since the mid-1990s, the National Science Foundation had funded many large partnerships, including many of those listed above, as collaborations mainly between consortia at universities and nearby public schools (e.g., Carlson & Simons, 1993; Gosselin et al., 2003; Mogk, 1996; The MSP Toolkit, 2003; Wagner et al., 1995; Wormstead et al., 2002).

Most recently, the National Science Teachers' Association began promoting partnerships as a way of promoting excellence and equity in science (Randolph, 2002). This might be viewed as an indication of the perceived success of collaborations and partnerships in advancing science education in the United States and elsewhere (The MSP Toolkit, 2003). As noted by Harnik and Ross, an educational shift toward partnerships in science education was part of a strong trend toward "more active engagement in scientific processes [that was] essential in order to adequately train future scientists and more importantly foster a general public able to make informed decisions from scientific information" (Harnik & Ross, 2003, p. 5). As a further indication of the success of partnerships and their perceived importance, the National Science Foundation encouraged that all scientific projects requesting funding contained a research and education component (Harnik & Ross, 2003).

Rationale for Collaboration, Partnership, and Authentic Science

In a paper on the rationale for partnerships, Tinker (1997) wrote that the traditional way that scientists supported pre-college education was through a scientist's lecture at a local school or supervising student research projects. Tinker noted that "this type of relationship rarely has a major impact on either students or scientists," but that a partnership represents a "two-way street of mutual interdependence and self-interest that [had] the capacity to grow and last" (Tinker, 1997, p. 111). Tinker (1997) suggested cost effectiveness, among other reasons, why scientists would want to become involved in partnerships. He distinguished scientist-led, scientist-guided, instrument-based, and student-originated as four main types of envisioned partnerships (mainly between student and scientist with teachers working as intermediaries).

Tinker was very straightforward when he said: "genuine student inquiry and investigations are a foundation that educators need on which to build student understanding of mathematics and science … it is only through their own inquiry that students learn the content and process of science" (Tinker, 1997, p. 113). This notion had been mentioned by many authors over the past decade, and again recently by Rahm et al., who said that only by "working at the elbows of scientists [could] students and teachers learn about the content and process of science while they come to participate in a wide range of studies of scientific phenomena" (Rahm et al., 2003, p. 738).

As Lawless and Rock (1998) pointed out, some good reasons why collaborations and partnerships worked so well for science education is that there was a parallel arrangement of steps in the scientific method and important educational objectives in the classroom. For example, they said that the observation step in the scientific method was comparable to awareness of nature in typical educational objectives for the classroom. Similarly, the next scientific step (scientific hypothesis), was comparable to inquiry and questioning. Modified slightly from Lawless and Rock (1998), this parallel arrangement is fully summarized in Table A1 (see Appendix A).

Bouillion and Gomez (2001), referring to the classic concepts of Vygotsky and other leading theorists, found that “learning is mediated by highly articulated tasks and activities in the social contexts of day-to-day living” (p. 878). They noted how the “patterns of activity from school often do not fit the more articulated activities that children observe or in which they participate after school.” They warned that “this disconnect can lead learners to perceive school learning as separate from life learning,” and further, “this decoupling leads to a disengagement in which some learners fail to see schooling as an avenue for life progress” (Bouillion & Gomez, 2001, p. 879). Their thesis mentioned a sort of scaffolding, which connected the real world and real science, which should exist in order for students to see science as meaningful and relevant.

In remarks to the 1996 national conference on “Student and Scientist Partnerships,” the director of the National Science Foundation recognized the current importance of partnerships (Lane, 1996a). Lane (1996a) stated that the idea of such partnerships was not really new, but we should look at it now with “fresh eyes” (p. 9) to see the value in “integration of [university] research and [public] education” (p. 9) to prepare students for the 21st century workplace. Lane noted that we must go “beyond the traditions of research in higher education and … understand and explore the possibilities of new partnerships between research and education at the primary and secondary levels” (Lane, 1996a, p. 9).

In the “Student and Scientist Partnerships” conference report, the rationale for partnerships was given as follows:

> [Partnerships] are facilitated by recent technological advances that have extended our ability to share and work with data and to communicate long distance. [Further], through student participation in authentic, real-time research, scientists acquire new research partners [while] students experience real science, learning up-to-date science content and developing essential investigation skills. (TERC & The Concord Consortium, 1996, p. 11)

The conference report noted that effective partnerships had three characteristics: “they depend on a serious collaboration between scientists and students, they engage students in research of real value to scientists, and they benefit both science and education” (TERC & The Concord Consortium, 1996, p. 11). The report noted especially the benefits of partnership endeavors, and the important role of the school teacher in the partnership (Lane, 1996a; Morse, 1996). Ledley et al. (2003) stated that any successful collaboration or partnership must provide benefits for all involved. Spencer et al. (1998) noted that enhanced skills derived from partnership experiences would encourage students to pursue careers in science and technology.

Among the many benefits to scientists cited by TERC and The Concord Consortium (1996) report were: more data collection and more effective sampling; ability to do ongoing monitoring; help with data analysis; creative insights and perspectives from students and teachers; promotion of public support for research; better teaching from partnership research; and higher service to society. Among the many benefits to students cited in the same report were the following: engagement in real research;

nurturing critical thinking; gaining a world view on science and research; validation of science studies; opportunities to learn complex subjects; contribution to the betterment of society; exposure to science and scientists; and fostering a sense of volunteerism and belonging. Barab and Hay (2001) noted these effects, but also pointed to a sense of ownership that might be achieved by the student and teacher that is important because of the perception that only scientists and textbooks possess new information. They described a sense of identity as a member of a community as well as the ownership issue as strong positive motivators for students in the partnership process.

Collaborations and partnerships helped students and teachers achieve the objectives within the National Science Education Standards (TERC and The Concord Consortium, 1996). The *National Science Education Standards* (National Academy of Sciences, 1995) emphasized that student learning of science greatly benefits from an inquiry approach (e.g., Science Content Standard A – Science as Inquiry) wherein students fully understood the concepts about processes shaping the natural world (e.g., Science Content Standard D – Earth and Space Science). These National Standards defined scientific inquiry as

> the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work … [and further such] inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (National Research Council, 1996, p. 6)

The National Standards said that science should be taught at all grade levels, must be meaningful and accessible to all students through inquiry methods, active learning, and activities that could build on what students already know, and that pre-college students should understand the basic nature of science (Lawless and Rock, 1998). The National Research Council (2000) noted that simple hand-on investigations are insufficient to achieve the National Standards' objectives and that science as process must be taught instead, preferably through some extended inquiry. The National Research Council (2000) viewed partnerships as an important mechanism for implementing needed science-education reforms (Buck, 2003). As noted in numerous references cited in this section, there was considerable support for the notion that inquiry-based approaches, as in collaborations or partnerships where students approach a problem much as a professional scientist would, best achieve the depth of learning of science that was described in the National Standards (Cannon, 2000; Hall-Wallace & Regens, 2003a; 2003b; Ledley et al., 2003).

Pedagogy in the Science Classroom

Communication

Pea (1994) addressed the concepts of communication for learning with a review of what he described as three views of communication: transmission, ritual, and transformative. The transmission and ritual views of communication have to do with communicating messages and with participation and fellowship, respectively, whereas the transformative view of communication had to do with "thinking and knowing … [that] is transformed by the process of communication"(Pea, 1994, p. 288). Pea noted that "when communication is viewed from [a] transformative perspective, not only students but also teachers are transformed as learners by means of their communicative activities" (Pea, 1994, p. 289).

Pea stated that "students are not blank slates written on with curricular lessons, (but rather) they are active learners who have … developed substantial beliefs and ways of thinking before ever coming to school" (Pea, 1994, p. 289). He added: "These existing conceptions and strategies are often best met and negotiated by the teacher in a conversation … (and) they are poorly dealt with by seeking to overwrite them with lectures" (Pea, 1994, p. 289). In transformative communication, teachers made a "significant effort" to "understand what students are thinking" and they might "develop new understandings of the subject domain by seeing how students … think about it" (Pea, 1994, p. 290). Further, Pea remarked that "highly interactive conversational exchanges requiring conjectures, responses, and repairs for all participants to determine what is meant from what is said and done" (Pea, 1994, p. 290). He commented that this kind of communication was too rare in current educational practice.

How People Learn

Donovan et al. edited a U.S. Department of Education-sponsored volume titled *How People Learn, Bridging Research and Practice*, which they described as "not a set of answers, but [rather] the basis for a conversation among researchers and practitioners about the kinds of knowledge, tools, and resources that would promote student learning and achievement" (Donovan et al., 1998, p. 8). Among their key findings were the following:

1. "Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp

the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom" (Donovan et al. 1998, p. 10).

2. In order "to develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application" (Donovan et al. 1998, p. 12).

3 A "metacognitive" approach to instruction could help students learn to "take control of their own learning by defining goals and monitoring their progress in achieving them" (Donovan et al. 1998, p. 13).

Donovan et al. listed parallel implications for teaching as follows:

1. "Teachers must draw out and work with the pre-existing understanding that their students bring with them" (Donovan et al. 1998, p. 15).
2. "Teachers must teach some subject matter in depth, providing many examples in which the same concept is at work and providing a firm foundation (of) actual knowledge" (Donovan et al. 1998, p. 16).
3. "The teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas" (Donovan et al. 1998, p. 17).

Libarkin et al. (2003) discussed four cognitive models namely: naïve mental models; unstable mental models; conceptual frameworks; and conceptual models. Naïve models were "intuitive and unconscious models used to interpret situations or knowledge" (Libarkin et al., 2003, p. 121). Unstable mental models were "inexact, incomplete, and used fluidly" (Libarkin et al., 2003, p. 121). Conceptual frameworks could be "organized, stable, and often-used mental models of the world" (Libarkin et al., 2003, p. 121). These first three models, according to Libarkin et al., were "generally used when discussing novice or naïve cognition" (Libarkin et al., 2003, p. 121). Conceptual models attended a "level of expertise" and are "external models" that were "representations of the world developed and used by expert groups to explain phenomena" (Libarkin et al., 2003, p. 122). Relating this to what Donovan et al. said above, naïve models, unstable mental models, and conceptual frameworks were "preconceptions" (Donovan et al., 1998, p. 10); whereas the goal of what Bell and Linn would call "knowledge integration" and "argument building" (Bell & Linn, 2000, p. 797) was student development and refinement of conceptual models by modifying their preconceptions. As Lovrich (2004) pointed out, this could be done from the top down ("when previous knowledge and experience is used to help identify stimuli" (p. 57)) or from the bottom up ("when simple characteristics of stimuli are observed and put into a pattern" (p. 57)).

Constructivism

Constructivism as a philosophical position dates from the works of Socrates and Plato, could be found in the 18th century philosophies of Kant and Locke, and has 20th century roots in the classic works of Dewey (reviewed by Wong et al., 2001), Piaget and Piaget and Inhelder (reviewed by Bosak, 1991; Crowther, 1999; Krampen, 1991; Phillips, 1994;), and Vygotsky (reviewed by Shapiro, 1994). Constructivism has been defined differently by authors, but generally it may be reduced to how "people make sense of their understandings of the world based on their prior experiences" (Keilborn & Gilmer, 1999, p. 13).

Piaget, who studied how children's minds develop, wrote about how children spontaneously respond to new ideas about the physical world (Bosak, 1991). Piagetian thought held that students do not learn so much from doing, but rather they learned more from "thinking about what they are doing" (Bosak, 1991, p. 7); and that students passed through stages according to age of being "operational" (p. 7), or being able to move back and forth through steps in a process (Bosak, 1991; Phillips, 1994). Similarly, Piagetian stages of children's drawings were reportedly related to their conceptions of space (Krampen, 1991).

In contrast, Vygotsky, who studied how children construct meaning, held that the "formal presentation of scientific ideas in school [should connect to] the child's approach to ideas about phenomena" (Shapiro, 1994, p. 35). Shapiro (1994) noted how Vygotsky distinguished nonspontaneous from spontaneous ideas, a distinction between ideas learned from books versus ideas arrived at by experience, respectively. In Vygotskian education, the teacher helped the student construct connections between nonspontaneous and spontaneous phenomena in the classroom.

Modern constructivism or constructivist education, as a way of addressing concerns over improved communication and ways to address how people learn, had gained strength in recent years. In the view of modern constructivists, learning involved knowledge that was "actively constructed by the individual [student] based on his or her prior knowledge rather than being added on or accumulated from new information" (Chang et al., 1999, p. 331). This contrasted with a more traditional "transmissionist" view that knowledge was “mostly transmitted or received by assimilation of understandings” (Chang et al., 1999, p. 331).

Crowther (1997) reported his view of constructivism: “that as we experience something new, we internalize it through our past experiences or knowledge constructs” (p. 2) and that “meaning is constructed by the cognitive apparatus of the learner” (Crowther, 1997, p. 3). Crowther reviewed various approaches to the constructivist classroom, which were summarized as follows: activities are “hands on” but lack the “recipe” formula where outcomes are strictly known; there was “active cognitive involvement” and “thinking out loud;” activities were in small groups that provided “expanded opportunities for cognitive restructuring;” and strong assessment of what students were doing (Crowther, 1997, p. 6). MacKenzie (2001) studied a constructivist middle-school classroom and noted the importance of “teacher stance,” which she defined as “wonder, curiosity, and exploration” during inquiry activities (p. 143). During these inquiry activities, “hypothetical situations were eagerly examined and pondered” (MacKenzie, 2001, p. 145). MacKenzie reported on the “mind-game bombs” of a particular middle-school teacher who approached constructivist lessons with statements such as: “How do you know?”, “What is your evidence?”, and “What makes you think this was true?” (MacKenzie, 2001, p.145–146).

Teaching and learning by encountering discrepant events were commonly used constructivist methods in inquiry-based classrooms (Appleton, 1996; Friedl, 1997; Liem, 1987). In discrepant event learning, students encountered something unexpected, an outcome that was unanticipated, or something happened that contradicts the student’s preconceptions about what should happen (Appleton, 1996; Liem, 1987). Appleton

(1996) referred to this phenomenon as cognitive conflict, which was based on the Piagetian idea of disequilibrium. Drawing from Piagetian theory, Appleton (1996) summarized the possible responses to cognitive conflicts as: (1) seeking a solution to explain what was seen; (2) ignoring or discounting what was seen; (3) adjusting mental schema to accommodate what was seen. In a literature synthesis, Appleton (1996) suggested three more-or-less distinctive ways that inquiry classrooms might typically respond to discrepant events encountered during inquiry. These were: (1) the teacher offered an explanation, which was accepted by students; (2) students asked questions and verbally explored hypotheses, which involved student discourse; and (3) students engaged in exploration, which involved student discourse with the teacher structuring the inquiry. Appleton concluded that the social context of constructivist lessons — in this instance, science lessons — was essential in attaining the "cognitive responses of students and their success in achieving understanding" (Appleton, 1996, p. 16).

Learning Environments

In a National Science Foundation-sponsored conference report, *Shaping the Future: Strategies for Revitalizing Undergraduate Education,* it was stated clearly that "the most effective teaching methods emphasize student learning in active, collaborative settings" (Lane, 1996b, p. 6). The report said further that students respond "enthusiastically to opportunities to learn science … through direct experience with the practice and process of inquiry" (Lane, 1996b, p. 6).

Various types of learning environments had been proposed and/or tested in order to engage students in collaborative and constructivist learning, including: open-ended or divergent questions (Carin & Sund, 1970); colloquium (Lansdown et al., 1971); debate projects (Bell & Linn, 2000); investigate and redesign projects (Crismond, 2001); everyday science (Roth, 1997); science-through-technology projects (Benenson, 2001; Cajas, 2001; Roth, 2001c); the Kids as Global Scientists program (Mistler-Jackson & Songer, 2000; Songer, 1996); on-line science support environments (Bell & Linn, 2000; Barnett et al., 2001; O'Neill and Polman, 2004; Schimmrich, 1996; Slater et al., 1998); open learning communities (Visser, 1999; Visser & Jain, 1996); state agency-school partnerships (Kopaska-Merkel, 2001); the ThinkerTool inquiry curriculum (White & Frederiksen, 1998); and many others.

All the studies cited reported evidence of success of these programs to varying degrees. Some cited specific points or design principles (Bell & Linn, 2000) that made them particularly successful. Among these principles were: connections to students' personal experiences; using designs that helped students visualize; interaction, note-taking, and discussions in real time; and promoting of social interaction during the work. It was important for students to have access to tools for inquiry and to be able to make choices about tools when engaging in classroom-based scientific inquiry (Jones et al., 2000). Jones et al. (2000) referred to tool space as equal in importance to conversation space in active inquiry. Three characteristics of tool space were: "access to tools, desire to use tools, and competition for tools" (Jones et al., 2000, p. 763). Social position and social dynamics of the group could limit an individual student's use of tools (Jones et al., 2000).

Focusing on the fourth grade, Herrenkohl and Guerra (1998) stressed the small group aspect of collaborative investigation. They noted how small groups of fourth graders could be effective in "generating, supporting, and building knowledge and understanding" in active learning situations (Herrenkohl & Guerra, 1998, p. 432). Herrenkohl and Guerra (1998) discussed moving beyond the traditional initiation-response-evaluation method of teaching (i.e., transmissionist teaching and learning; Chang et al., 1999) and instead using "participant structures, scientific discourse, and student engagement" (Herrenkohl & Guerra, 1998, p. 432). The suggested tools they mention were: "coordinating theories and evidence, predicting prior to experimenting, and understanding the features that distinguish scientific explanation from everyday notions" (Herrenkohl & Guerra, 1998, p. 436). They noted that "science is not a body of facts to be mastered but rather a systematic way of building models about phenomena" (Herrenkohl & Guerra, 1998, p. 436). Herrenkohl and Guerra stated that "metacognitive reflection is the central part of encouraging students to think scientifically" (Herrenkohl & Guerra, 1998, p. 437). They advocated three basic features of active learning: "monitoring comprehension" by asking clarification questions; "challenging others' perspectives and claims" by discussing plausibility; and "coordinating theories with evidence" (Herrenkohl & Guerra, 1998, p. 440–441).

In middle-school classrooms, Krajcik et al. (1998) found similar results to the study of fourth graders noted above. Krajcik et al. (1998) discussed project-based science classrooms wherein students worked on projects over sustained periods of time. They noted that middle-school students were "thoughtful in designing investigations and in planning procedures" but were less effective in systematic data collection and analysis without constant "teacher structuring and questioning" (Krajcik et al., 1998, p. 313). Several studies documented similar success and potential weakness with high-school and early college-level students (Boyd, 1980; Burnley, 2004; Henson, 2003; Macdonald et al., 2000; Powell, 1981; Songer, 1996; Sternadel, 2004). Teachers were similarly affected in positive ways by the collaboration process (Bell et al., 2003), including elementary teachers (Levitt & Manner, 2001; Riggs & Enochs, 1990; Stallings et al., 1981) and teachers of kindergarten through grade twelve (Bower, 2002; Calhoun et al., 2003; Jones et al., 1998; Kean & Enochs, 2001; Slattery et al., 1999).

White and Frederiksen (1998), Pearce (1999), and Costa (2001) stressed the metacognitive process in their research. White and Frederiksen (1998) broke the metacognitive process into two parts: the inquiry cycle and the reflective assessment. The inquiry cycle generally started with a question, which led to some prediction and this was followed by experimentation, model development, and application of the model, which led to more questions and then completes the cycle. The reflective assessment allowed students to develop a deeper understanding of the inquiry cycle. In this process, both self- and peer-assessment is involved. After the reflective process, students returned to the question point in the research cycle. According to White and Frederiksen, middle-school students they worked with who had difficulty with science had this difficulty not because they were “too young or lack intelligence,” but rather “they simply do not know how to construct conceptual models of scientific phenomena and how to monitor and reflect on their progress” (White & Fredericksen, 1998, p. 5). Further, they noted: “if you also teach them how to monitor and reflect on their inquiry processes, then they can engage in inquiry and learn (science) as well as older or higher achieving students” (White & Fredericksen, 1998, p. 6).

Seiler et al. (2001) examined “activities that emphasize design and technology” with classes of “inner city African American students from life worlds characterized by poverty" (p. 746). They noted student interactions that "suggest design and technological competence," but that there was also "evidence of resistance from students … who refused to cooperate" (Seiler et al., 2001, p. 746). They noted that "analysis of in-class interactions reveals an untapped potential for the emergence of a science-like discourse and diverse outcomes … among the challenges explored in this article is a struggle for respect that permeates students' lives" (Seiler et al., 2001, p. 746). They concluded that students used the class opportunity to maintain and earn respect of others. Seiler et al. discussed the high potential for learning and achievement by students "when the curriculum is centered on their interests and involves them actively" (p. 748).

Roth (1997) discussed what made learning environments authentic. He referred to knowledgeability in authentic environments. Knowledgeability was a "state of change" that has several aspects, including (1) "people [being] related in multiple and heterogeneous ways" [the emphasis on the social nature of cooperative work], (2) people improvising and experiencing failure, and (3) people drawing on the experience and expertise of others (Roth, 1997, p. 379).

Hammer and Schifter (2001) added another perspective to this kind of inquiry, suggesting that teachers practicing authentic inquiry should become in effect researchers of their own classrooms. They found "teachers, similar to researchers, [should] observe, collect data, inquire, and draw inferences about learners' understanding and reasoning" during the lessons (Hammer & Schifter, 2001, p. 442). According to Hammer and Schifter, teachers should "inquire toward action in the context of their classes … and to the benefit of their students" (p. 456).

Student Behavior

Roth and McGinn (1998) discussed the lack of learning environments wherein students can do investigations in an authentic way involving “problem posing, problem solving, and persuading peers” (p. 216). Roth and McGinn (1998) also pointed out that learning environments typically did not take into account the central role of visual representations in science and technology. They encouraged investigators to focus on what students’ behavior is like when they were actively learning by doing and what students actually did in the classroom laboratory. Roth and McGinn (1998) discussed inscriptions, which they defined broadly as visual representations of nature. They noted that scientists and engineers constantly engaged inscriptions, and suggested so should an inquiry classroom. Inscriptions, Roth and McGinn (1998) found, served as means to engage others in thought and conversation, focused others’ attention, and coordinated and constrained activities and conversations. Roth and McGinn viewed inscriptions as so important that “they allow people to cooperate despite not having good models of each others’ understandings … and having different goals” (p. 217). Roth and McGinn noted that students similarly use inscriptions, which in the instance of this study would be photomicrographs (images made with the digital microscope) and related drawing and art works.

Roth (1994) presented the view that students would communicate their findings in an inquiry-based classroom in much the same way that scientists communicated in their work as long as they were allowed to do so. Roth pointed to the three communicative elements, “hands, eyes, and signs” (p. 170), and noted their interdependence in classroom communities of learning. Roth argued that “scientific talk” was much like other forms of communication in that it necessarily involves “the synchronicity of verbal action, inscriptions, pointing and gesture, body movements, and rhythm” (Roth, 1994, p. 171). Student members of the classroom community would naturally engage in sense-making conversation when working together, but students who were isolated might be stymied (Roth, 1994). In this study, Roth (1994) examined the effect of a representational device, in this instance a chalkboard. However, this representational device could have been any device that allowed students to express themselves in its use. According to Roth, “when all participants had access to the representational device … efficient communication occurred … in a way that is characteristic of talk in a scientific laboratory” (p. 180). Roth used the term “authentic argumentation” (p. 180) to name this classroom phenomenon.

Materials, gestures, and bodily movements all played a role in the “emergence of students’ science-related discourses” (Roth, 1999, p. 27). A central theme of the research by Roth (1994; 1999) was that more than just what students say was important in their learning interactions (and understanding their learning interactions). Roth’s (1999) study emphasized the importance of a classroom laboratory setting where students could work and interact. Roth (1999) documented the firm connection between phenomenological understanding gained by students interacting with materials and other students and the conceptual understanding they might have gained or tried to gain from a lecture or reading. Students discovered the meanings of new terms and concepts in the process of creating new physical situations (Roth, 1999). In the learning process, students interwove discussion and bodily movements (including gestures) in gaining new understandings.

Roth (2000), Roth and Welzel (2001), Roth (2003), and Roth and Lawless (2002) discussed the specific function of gestures in student learning behavior. Roth viewed these as having “a transitional function between ergotic/epistemic movement of hands and symbolic expressions” (Roth, 2003, p. 141) in the process of new investigation in a science classroom. Roth found that “student communication is distributed across the context” and “shifts increasingly into a verbal modality as students become more familiar with the phenomena they are to learn about” (Roth, 2003, p. 141). Initially, there was a time delay between student gestures and the corresponding verbal expressions, but this time delay decreases with increasing familiarity. Roth emphasized that student communications (gestures and talking) while in the presence of the material to be studied, had an important cognitive function and that gesturing, acting, talking, and making graphic representations helped form a “scaffold to the student’s cognitive development” (Roth, 2003, p. 165) Roth and Welzel noted that “gestures provide a medium on which the development of scientific discourse can piggyback” and “gestures allow students to construct complex explanations in the absence of scientific language” (Roth and Welzel, 2001, p. 103). Roth and Lawless (2002) noted how gestures were important in students’ moving from an initial stage of what they called muddled talk to more sophisticated communication of ideas.

Roth (2001a) observed that knowing and learning in the classroom involves students’ arriving at what they called stable language for description of the phenomena they were studying. In order for this to happen, students’ descriptive language evolved as they studied the materials in the classroom laboratory. Roth stated that “new forms of descriptive language emerge from older forms (vernacular) that students find to be inappropriate in the course of their unfolding activities” (Roth, 2001a, p. 43). Eventually, the many words and terms used tended to converge on a pattern of word use. In this way, new meanings and understandings could arise from small group interactions (Roth, 2001a; 2001b). Roth (2000) noted that with increasing familiarity, scientific talk took on increased importance over gesturing and use of non-scientific terms in the classroom activities.

Roth et al. (1999) studied the interactions of focal artifacts (things to look at and/or study), social configurations, and physical arrangements upon students' science conversations during learning activities. In an important finding, they noted that "students' utterances were not so much properties of individuals but evidence of more general assumptions implicit in the common ground shared in the classroom community" (Roth et al., 1999, p. 297). Roth et al. discussed the need for providing a "forum for conversation" as well as "explicitly organizing learning environments around physical artifacts with the goal of developing a shared discourse" (Roth et al., 1999, p. 297). In this environment, the artifacts "provide anchors or bridges" across groups or between individuals, who may have different backgrounds and levels of understanding (Roth et al., 1999, p. 298). These disparate groups or individual students comprise what they called communities of practice, according to Roth (1995) and Roth et al. (1999), who pointed to the more experienced or insightful students as leaders in these communities.

Roth (1996b) studied "knowledge diffusion" in elementary students whose classroom "was transformed as a tool (glue gun) and associated practices came to be shared by the members of the classroom community" (p. 179). The community, which was studying a unit on civil engineering, transformed as students with "peripheral participation" entered full participation as the "newcomers learning at the elbows of their more competent peers" (Roth, 1996b, p. 179). Roth reported that the adoption of this one tool “transformed the very setting in which students learned” (Roth, 1996b, p. 179). In Roth’s view, the ease with which “student-centered adoption” of the new tool was accounted for by “actor network theory,” which was a successful approach for understanding knowledge construction and diffusion in science and technology (Roth, 1996b, p. 179). It was in Roth’s view a way of understanding classroom behavior according to observed causes and effects and how actors interact with one another by talking and gesturing. Roth (1996b) represented that cognition arises from the interaction of the task, the individual, and the physical and social setting. Roth went on to say that “individual (students) move along trajectories from being newcomers to becoming old-timers” (Roth, 1996b, p. 179) within a classroom community.

In studying student behavior, Roth (1995; 1996b) used what he called tracers. Roth defined tracers as “artifacts, procedures, actions, talk, or written symbols that allowed researchers to identify and trace students’ understanding in different contexts or settings” (Roth, 1996b, p. 193). Roth (1995; 1996b) employed several tracers in order to help understand how knowledge diffused through a community of practice. Roth (1996b) noted that students reveal tracers as they move through different stages of competence in using tools or concepts. Tracers arose from one or a small group of students (i.e., the principle actors of Roth 1996a) and then diffuse through the group as students talked and gestured, and students observed each others’ work. Roth (1996b) remarked that his observations indicate that tool-related tracers move more slowly than other types of tracers within a classroom community. However, the introduction of tool-related tracers, Roth noted, increased the level of interaction among students in the community and tended to restructure the community, especially where tools were a limited resource in the classroom. Roth (1996b) noted especially that tool-related practice stimulated the incidence of peer teaching among students. Roth went on to say that the effect within a classroom community of new tool technology was “indeterminate in that it cannot be predicted” with much certainty (Roth, 1996b, p. 212). Unexpected effects tended to “ripple through the community” as actors (students) communicate to others about tool use (Roth, 1996b, p. 213).

Several of Roth’s papers (1999; 2001a; Roth & Welzel, 2001) challenged some well established notions from the classic works of Piaget and Inhelder and Piaget. According to Roth (1999), Piaget firmly established the idea of a strong connection between student experience and knowledge, including the distinction between objects leading to concrete knowledge and actions leading to formal concepts. Yet, Roth (1999) held that “highly abstract concepts … and their relations are grounded in bodily experiences” (p. 29). Roth (1999) referred to this as a phenomenological understanding. Based on watching hundreds of hours of video-taped lessons showing students and how they respond to questions about the physical world during inquiry lessons, Roth (2001a) asserted that the structure of the students’ focal phenomena was different from what had been previously assumed. Roth and Welzel (2001) found that gestures helped the student grasp what was going on as they moved toward a more grounded understanding of what they were seeing and doing.

Jones et al. (2003) studied the behavior of students who were looking for the first time at nano-scale biologic structures using a remotely operated microscope. They discussed the Piagetian concept of haptic perception among student microscope users. Haptic perception, which involved perception via touch as well as sight (magnified in this instance), was a key mode by which students learn about the physical properties of objects beyond their everyday perceptions. Jones et al. (2003) noted that "encouraging students to create linked image and linguistic representations … facilitates learning" of content material (p. 305). They remarked on the ways that "technology-mediated inquiry" (i.e., microscopic study remotely viewed on a computer screen) "allows for social construction of knowledge" (Jones et al., 2003, p.306). Regarding student interactions they observed, Jones et al. saw the computer-based microscopy as "a vehicle for conducting and sharing science" (Jones et al., 2003, p.306). One of their primary research questions concerned the effect of computer-based microscopy on student learning in a classroom setting. Jones et al. (2003) reported that students significantly advanced their understanding of shape and scale as a result of the computer-based lessons.

Teacher Change

Richardson (1990; 1991) noted that many studies suggested teachers in general were resistant to change. Richardson (1991) noted, however, that teacher change was well documented in educational literature and generally fell into two main types: program implementation and teacher learning. Richardson synthesized previous work in teacher change by saying that an individual teacher's decision to change lay mainly with "an individual's beliefs, attitudes, goals, and knowledge" and "cues from the organizational environment" (Richardson, 1990, p. 11). Richardson also noted that previous work indicates three factors, namely (1) practicality ("Does it allow for classroom contingencies?"), (2) situational ("Does it fit my classroom situation?"), and (3) cost, were important to most teachers when they consider change (Richardson, 1990, p. 11). Richardson defined "teacher change" (with regard to program implementation) as "doing something that others are suggesting they do" (p. 69). In addition, Richardson described the teacher learning aspect of teacher change. In teacher learning, Richardson said, it was fundamental to look at "what teachers do and how they do it, why teachers do what they do, and why teachers begin to do something differently" (Richardson, 1991, p. 70-71). Richardson also noted that it was important to consider how teachers think and what they believe. These things varied over the span of a teacher's career and mainly had to do with experience level and what Richardson called the teacher as a person. For example, Richardson noted that "expert teachers perceive and process visual classroom information" differently from novice and inexperienced teachers (Richardson, 1991, p. 71). About the role of the teacher as a person, Richardson (1991) remarked that previous work suggested how closely tied teacher beliefs were to their own perceptions of themselves as learners and students. Richardson (1991) referred to teacher self-perceptions collectively as the teacher's personal biography. Speaking about her research, Richardson (1991) remarked, "the strong relationships among the individual teacher's perceptions of how he or she learned [the subject at hand], how students learn [the subject], what [the subject] is, and the actions taken by the teacher in the classroom became quite clear in interviews" (p. 78).

Richardson (1990) took the view that contrary to some published teacher-change studies, the teachers that Richardson observed "changed all the time." In elaborating, she distinguished between first-order and second-order change. First-order change related to trying new kinds of activities, whereas second-order change involved large-scale restructuring of a curriculum or school. Whether first- or second-order, teacher change hinged on three basic questions, according to Richardson (1990). These questions were:

“Who is in charge of the change?”; “What is the focus of the change?”; and “What is significant and worthwhile [in the change]?” (Richardson, 1990, p. 13). Considering these questions, Richardson (1990) noted that “individual teacher change should be viewed within the culture and norms of a collective of teachers, administrators, and other personnel, and students in a particular school” (p. 14). Richardson and Anders (1994) also noted that study of teacher change should include classroom observations, interviews at the outset and end, and a follow-up study (two to three years later). Senger (1999) pointed out that teachers changed gradually over time and develop “experimental beliefs” (p. 209) as they integrate changes.

Motivation was an important factor in teacher change, as noted by Frase and Conley (1994). They pointed to eight areas of what they called profound knowledge as being keys to motivation in teachers. These included appreciation for the educational system, understanding where success and lack of success really came from, understanding the strengths and weaknesses of human predictions, understanding human psychology, appreciating being caught up in what a person liked to do, finding intrinsic motivation in the work of teaching, believing that there was no limit to accomplishment and notion of self-worth, and having a can-do attitude. Frase and Conley (1994, p. 30) concluded their findings about motivation by quoting Emerson, “The joy of a thing well done is to have done it.”

Student Conceptions

About Scientists and Science

Students commonly held alternative conceptions of scientists and about science. As Carlson (2001) found, in a study of student preconceptions about scientists, that most students regarded scientists as older, bearded, Caucasian men who spent time in laboratories and wear white coats and are surrounded by what they called symbols of knowledge such as computers, clipboards, and books. Most students surveyed remarked that they planned to stop taking science and mathematics courses as soon as possible, but it was revealed that they lacked the understanding that such courses could help them with their careers (Carlson, 2001). Carlson (2001) noted that when asked to draw a picture of themselves as scientists, the vast majority (86%) of students did not incorporate the stereotypical preconceptions noted above, but rather depicted themselves participating in an activity.

Tytler and Peterson (2004) noted that “until early adolescence, children tended not to think of theory and evidence as separate entities” (p. 95). The implications of this lack of distinction were profound and tended to impose a “fundamental constraint on young children’s science conceptions” (Tytler &Peterson, 2004, p. 95). They also noted that “children’s conceptual change and their growth in scientific reasoning are fundamentally driven by a growth in domain-specific knowledge” (Tytler &Peterson, 2004, p. 95). They remarked that young children needed to be presented with “clearly distinguishable hypotheses that [were] refutable … and did not place high knowledge demands or offend prior beliefs” (Tytler &Peterson, 2004, p. 96).

Studies have commonly shown that students, regardless of age and grade level, have significant erroneous or partially correct preconceptions about science and the nature of science (e.g., Hawley, 2002; Libarken, 2001; Schoon, 1992). In a study of student conceptions about Earth and space science, Schoon (1992) found that alternative conceptions fell into three groups: “primary alternative conceptions” (i.e., “those that were chosen more often than the scientifically acceptable conception”); “secondary alternative conceptions” (i.e., “those which were chosen less often than the scientifically acceptable conception”; and “functional alternative conceptions” (i.e., “those which could interfere with one’s ability to function in society”) (p. 209–211). Schoon noted the identified misconceptions were found across racial groups, economic status groups, educational levels, and between genders.

Kusnick (2002) identified what she called conceptual prisms in the development of incorrect student preconceptions (i.e., misconceptions) about science. She defined conceptual prisms as the result of “interaction of the student’s world view and personal experiences” (Kusnick, 2002, p. 31). Conceptual prisms were “deeply held” and “largely unexamined” beliefs, and these beliefs were “largely unaffected by traditional science instruction” (Kusnick, 2002, p. 31). Kusnick noted that students “experience instruction refracted through their conceptual prisms, resulting in a spectrum of student ideas” about science (Kusnick, 2002, p. 31). Research on student preconceptions “arises from a constructivist view of science learning, [which] posits that learning is a complex process in which instructional experiences interact with the learner’s existing beliefs, experiences, and knowledge” (Kusnick, 2002, p. 31). A student’s world view, as noted by Kusnick (2002), could be formed by culture, religion, family, personality, and psychology. She noted that transmission schooling had but a weak impact on forming student preconceptions about science.

Students generally had difficulty in reading images in science texts for the same reason as they have difficulty in assimilating new conceptual models of science (Colin et al., 2002; Pintó & Ametller, 2002; Stylianidou et al., 2002). Stylianidou et al. (2002) noted this was due to what they called students' preexisting theoretical lenses though which they viewed the world and printed diagrams in science texts. These theoretical lenses were essentially the same thing as what Kusnick (2002) called conceptual prisms.

About the Natural World

Chi et al. (1994) broke down student conceptions into three ontological categories (i.e., matter, process, and mental state) and said that it is critical that students identified what category or categories they were dealing with before it is possible to effectively modify their conceptions. In the matter category, for example, students would be thinking whether something was artificial or man-made, living or non-living, solid or liquid, etc. In the process category, students would ponder random versus chaotic, intentional versus unintentional, something that started at a point versus a cyclical process, etc. In the mental state category, students would consider, for example, was this true or not true, or did this arise from fear or desire. Chi et al. (1994) noted that conceptual change between ontologically compatible concepts was easy, but change was quite difficult when incompatible concepts are involved.

Students, whether pre-K, K–2, or college, commonly hold alternative conceptions about the physical, chemical, and biological world that fitted their experiences but did not fit scientific accounts of the natural world (Gelman &Brenneman, 2004; Libarkin

&Kurdziel, 2001; Stylianidou et al., 2002). As pointed out previously, these conceptions were important and must be addressed in order for them to be changed. Libarkin and Kurdziel (2001) advocated probing misconceptions by administering questionnaires, but other researchers addressed this issue in discussions and debates during active research (e.g., Hawley, 2002; Kusnick, 2002), especially active research focused on the local environment (e.g., Ford, 2003).

Nakhleh and Samarapungavan (1999) studied 7- to 10-year old students concerning their beliefs about matter. They found a range of beliefs from macrocontinuous (there are no smaller, invisible parts within solids, liquids, or gasses) to microcontinuous (all matter is made up of much smaller parts that we do not see). They noted that twenty percent of students they studied held each of these views, and that the majority (sixty percent) studied held intermediate views. The intermediate view (macroparticulate) consisted of a range of notions that might include smaller components within the larger whole. Nakhleh and Samarapungavan's (1999) conclusion was that "children first developed local frameworks particular to different classes of substances and then slowly expand these frameworks to include a wide range of substances and their properties" (p. 777). They noted that the young students' conceptions had ontological coherence even though they were not correct in most cases. Jones et al. (2003) took up the issue of what children thought about the world that was too small to be seen. They noted significant changes in the perceptions of children about nano-scale objects after they were exposed to work with a microscope. Similar results were reported by Gerking (2003) regarding students exposed to inexpensive, yet sophisticated telescopes.

In a review of the study of mental representations constructed by students, Greca and Moreira (2000) discussed mental models, conceptual models, and modeling as a process. They defined mental models as “knowledge representation that is implicit, incomplete, imprecise, [and] incoherent with normative knowledge in various domains” (Greca & Moreira, 2000, p. 3). They added that mental models were “never complete [but] continue to be enlarged and improved as new information is incorporated into it” (Greca & Moreira, 2000, p. 4). They defined conceptual model as “an external representation created by researchers, teachers, engineers, etc., that facilitates the comprehension or teaching of systems or states of affairs in the world” (Greca & Moreira, 2000, p. 5). They described the modeling process “as the learning of a series of steps to identify only those salient elements of a system, and to evaluate, according to distinct rules, the chosen model,” and they likened modeling to “learning the new language” that would “allow for another perception of the description of the phenomena” being studied (Greca & Moreira, 2000, p. 7).

When probed about their concepts of natural materials (rocks, insects, etc.), young children tended to emphasize the nature of these materials in relation to themselves, e.g., how they made them feel or how they looked and what they felt like (Ford, 2003; Hawley, 2002; Shepardson, 2002), which was a Piagetian concept about younger children (Bosak, 1991). Older students were able to provide more detailed concepts about natural materials, and this was perhaps a reflection of their additional experience in the natural world (Bosak, 1991; Ford, 2003; Shepardson, 2002; Tomkins & Tunnicliffe, 2001). Smith et al. (1985) noted that younger students (3- to 9-year olds) showed progressively increasing sophistication in being able to articulate the concepts of weight and weight-for-size (i.e., density). Younger students grasped the concept of weight (in a relative way), but older students were the ones who could articulate weight and weight-for-size distinctly. This paralleled the reported increase in sophistication of description for insects reported by Shepardson (2002).

Regarding the nature of science, McComas et al. (2000) reviewed the pioneering ideas of Thomas Kuhn saying that the science textbook, more than any one thing, had affected the views about science and scientists held by teachers and students. McComas et al. (2000) noted that science textbooks left out the process of science and thus teachers and students did not typically understand where ideas come from. In particular, they pointed out that the non-empirical side of science was missing and therefore made it seem as if science was all facts that had been discovered without much searching and inquiry. They noted that in inquiry settings, the students had an opportunity to see what science was really like.

Despite some of the differences between adults and children noted above, there was a natural connection between a child's approach to nature and that of a scientist, as noted by several researchers (e.g., Roth, 2003; Roth & McGinn, 1998). According to Pearce (1999),

> every child is a scientist … children think in ways that scientists think, say things that scientists say, and do things that scientists do … what pure science it is when a child touches and feels, tastes and smells, examines and manipulates … children are driven to fully examine all they can in their surroundings. (p. 3)

Liem (1987) added that children were naturally excited about scientific discovery and drew also from a teacher's excitement about scientific discovery.

About Art and Science

According to Gehlbach (1990), art was difficult to define and was generally difficult to teach. Further, art education was generally restricted to visual, static art, which was produced by the individual. Gehlbach (1990) distinguished two types of art in the educational context: expression art and communication art. Expression art was the work of artists in particular, whereas communication art might serve other purposes (for example, replacing or enhancing written communication or in science). Gehlbach (1990) noted that expression and communication art would be decoded by those who saw it, in other words a particular significance would be attached to the art by others.

Wright (2000) discussed the similarities between art and natural science from the point of view of practitioners of both fields. She added that artists were concerned simultaneously with the "inner world of ideas and vision and [at the same time] a practical world of materials and technique" (Wright, 2000, p. 284). Natural scientists, she added, experienced this same duality in that they must deal with the material qualities of things in nature and yet at the same time ponder their visions of the hidden qualities of natural things and their place in nature. Wright's (2000) study dealt mainly with geological themes as have several other authors (e.g., Chan, 1993; Grall-Johnson, 2000; Hall, 2005; Mieras, 2000; Pestrong, 1994; Rosenberg, 2000). In addition, some authors had presented artistic microscopic views of natural world and the world of tiny crystals (Dabdoub, 2003; Davidson & Lotus, 1993; Rotner & Olivo, 1997). Part of the thesis of all these authors was the view summarized by Wright who noted that studying natural materials for their scientific and artistic qualities involved mixing "materiality and inner vision" (Wright, 2000, p. 286). Another part of a common thesis of these researchers was expressed by Pestrong by saying that when studied closely, the artistic qualities of natural materials may help “attract and hold the interest of those students who might be disinterested in science or the arts” (Pestrong, 1994, p. 249). Smith and the Drawing Study Group (1998) compared drawing to scientific inquiry, as the ancient Greeks did.

One of the most popular artists whose name was associated with a strong bond with nature was Georgia O’Keeffe (1887–1986). O’Keeffe was best known for her paintings of magnified flowers and New Mexico landscapes (Benke, 2000; Robinson, 1989). O’Keeffe was a student of the school of art that emerged in the early 1900s that advocated an artist should evoke feelings about the hidden world of the natural art object (Benke, 2000). Benke (2000) noted that the artist Georgia O’Keeffe wanted to make small things like flowers larger so that people would notice them in her paintings and would begin to think about them. She described Georgia O’Keeffe’s works as complete, large-size views of flowers and natural objects. Benke noted that the O’Keeffe style was “extreme close-up, as a result of which the outer edges of the leaves and stems are often cut off,” and noted that the work of Georgia O’Keeffe was “an immediate response to her environment” (Benke, 2000, p. 31). Benke (2000) remarked that O’Keeffe was fascinated by flowers as a result of an art teacher’s bringing flowers to class one day during her early schooling in Madison, Wisconsin. She remarked that the sight of a tiny flower inspired O’Keeffe to paint magnified flowers. O’Keeffe was quoted as saying:

> A flower is relatively small … everyone has many associations with a flower – the idea of flowers … still in a way nobody sees a flower – really – it is too small – we haven’t the time – and to see takes time … so, I said to myself – I’ll paint what I see – what the flower is to me but I’ll paint it big and they will be surprised

into taking time to look at it – I will make even busy New Yorkers take time to see what I see of flowers. (Benke, 2000, p. 31)

Benke (2000), who carefully examined the life of Georgia O'Keeffe, noted that she used what Benke called an exalted way of seeing, which followed the view of the Romantic poet William Wordsworth (1770–1850). Wordsworth said "To every natural form, rock, fruit, or flower, even loose stones that cover the highway, I gave a moral life, I saw them feel, or linked them to some feeling" (Benke, 2000, p. 37). Many art teachers today incorporate art lessons that were inspired by Georgia O'Keeffe.

Microscopy and Digital Microscopy

History of Microscopy

Timeline in Optics

According to Davidson (1995–2004), "optics is the physical science that studies the origin and propagation of light, how it changes, what effects it produces, and other phenomena associated with it" (p. 1). He went on to say "there are two branches of optics. Physical optics is concerned with the nature and properties of light itself [and] geometrical optics deals with the principles governing image-forming properties of lenses, mirrors, and other devices, such as optical data processors" (Davidson, 1995–2004, p. 1).

Davidson (1995–2004, p. 1) presented the following "Timeline in Optics," which "highlights important events and developments in the science of optics from prehistory to the beginning of the 21st century. It also included related developments in other fields (e.g., the evolution of computers) and related milestones in the human worldview.” The following series of subheadings are taken from Davidson (1995–2004, p. 1–2).

> *Prehistory to 999* — Thousands of years after humans started using fire to illuminate the night, Greek and Arab scholars began to formulate theories of how light was propagated, how it could be reflected and refracted, and how it was perceived by the eyes.
>
> *1000 to 1599* — Arab and Chinese scholars experimented with light, lenses, and mirrors for several hundred years, but interest waned. In Medieval Europe, Copernicus launched the scientific revolution with his shocking theory that the Earth revolved around the Sun.
>
> *1600 to 1699* — Microscopes and telescopes broadened the worldview of early scientists and the scientific revolution culminated with the publication of Isaac Newton’s *Principia*.
>
> *1700 to 1799* — Newton published *Opticks*, discussing the corpuscular theory of light, and scientists established procedures for the scientific method. Herschel discovered Uranus, and a few scientists began to study electricity.
>
> *1800 to 1833* — Newton’s corpuscular theory of light was overturned by the wave theory of light, scientists discovered invisible infrared and ultraviolet light, and the first photographic image was recorded.
>
> *1834 to 1866* — Photography underwent major developments, the speed of light was measured accurately for the first time, the new field of spectroscopy was introduced, and Maxwell theorized that light is a type of electromagnetic wave.

1867 to 1899 — Hertz proved that light was an electromagnetic wave, Michelson and Morley showed that there was no ether permeating space, Tesla and Marconi invented radio, and Eastman invented photographic film.

1900 to 1933 — Einstein and Planck revolutionized physics, and physicists now regard light as both a wave and a particle. In addition, radio became a popular broadcast communications medium, television was invented, and Tombaugh discovered Pluto.

1934 to 1966 — The first electron microscope was built, television became more popular than radio, and a host of new technologies were introduced – the laser, holography, fiber optics, and computers. Space exploration began.

1967 to 2004 — Video games were invented, people visited the Moon, robots visited Mars, and personal computers launched the digital revolution. Lasers and fiber optics created new media for communications, information storage, and entertainment. Cyberspace became a reality with the creation of the global Internet.

Evolution of Microscopes

According to Bellis (2004), even though eyeglasses with glass lenses existed from the 13th century, the first microscopes were produced in the late 16th century and consisted of a simple "tube with a plate for the object[ive] at one end and, at the other, a lens which gave a magnification less than ten diameters" (p. 1). These devices were called flea glasses because they were used to enlarge common things like fleas for entertainment purposes. These early compound microscopes were thought to have been invented in about 1595 by Zacharias Janssen and his father Hans Janssen (Davidson, 1995–2004). Bellis (2004) gave this brief account of the origins of microscopy:

> The father of microscopy, Anton van Leeuwenhoek of Holland (1632–1723), started as an apprentice in a dry goods store where magnifying glasses were used to count the threads in cloth. He taught himself new methods for grinding and polishing tiny lenses of great curvature which gave magnifications up to 270 diameters, the finest known at that time. These led to the building of his microscopes and the biological discoveries for which he is famous. He was the first to see and describe bacteria, yeast plants, the teeming life in a drop of water, and the circulation of blood corpuscles in capillaries. During a long life he used his lenses to make pioneer studies on an extraordinary variety of things, both living and non living, and reported his findings in over a hundred letters to the Royal Society of England and the French Academy. (p. 1–2)

Bellis (2004) added:

> Robert Hooke (1635–1703), the English father of microscopy [and author of the first book on observations through a microscope, *Micrographia*], re-confirmed Anton van Leeuwenhoek's discoveries of the existence of tiny living organisms in a drop of water. Hooke made a copy of Leeuwenhoek's microscope and then improved upon his design. Later, a few major improvements were made until the middle of the 19th century. [In the 20th century, the U.S. and] several European countries began to manufacture fine optical equipment. Present day instruments, changed but little, give magnifications up to 1,250 diameters with ordinary light and up to 5,000 with blue light. (p. 2)

Of the inherent limitations of light microscopy, Bellis (2004) wrote:

> A light microscope, even one with perfect lenses and perfect illumination, simply cannot be used to distinguish objects that are smaller than half the wavelength of light. White light has an average wavelength of 0.55 micrometers, half of which is 0.275 micrometers. Any two lines that are closer together than 0.275 micrometers will be seen as a single line, and any object with a diameter smaller than 0.275 micrometers will be invisible or, at best, show up as a blur. To see tiny particles under a microscope, scientists must bypass light altogether and use a different sort of 'illumination,' one with a shorter wavelength. (p. 2)

Development in the 1930s of the electron microscope allowed objects as small as 10 angstroms, or the size of some atoms, to be seen, albeit indirectly via an electron beam-created image (Bellis, 2004).

Around the beginning of the 20th century, mineralogists and petrologists (i.e., geologists who study minerals and rocks, respectively) began to modify compound microscopes by inserting a polarizing plate between the object being viewed (i.e., a thin section, a ~ 30-micron thick, slice of a mineral or rock that was glued to a glass slip) and the objective (lower lens) of the microscope (Gunter, 2004). As Gunter noted, this modification, which was called the polarizing light microscope had "no doubt contributed more to our knowledge of minerals and rocks than any other single instrument" (Gunter, 2004, p. 34). In the 1960s, thin section study using cathodoluminescence, "a phenomenon when a thin section is bombarded by an electron beam" was introduced (Kopp, 1981, p. 109). Luminescence was the phenomenon of minerals "emitting visible light … when it is bombarded with some other form of energy" (Kopp, 1981, p. 109). In cathodoluminescence petrography, fine-scale structures of minerals could be seen by the colors they emit. These colors related to trace-element compositional differences in layers within minerals.

Nature of the Microscope

The modern light microscope was a compound microscope, which meant that there are two lenses in the "optical train" (i.e., the light path), the objective lens that is close to the specimen and an ocular lens (or eyepiece) that was near the operator's eye (Davidson, 1998-2004, chap. 1, p. 1). Davidson described the modern compound microscope as follows: "The optical components contained within modern microscopes are mounted on a stable, ergonomically designed base that allows rapid exchange, precision centering, and careful alignment between those assemblies that are optically interdependent. Together, the optical and mechanical components of the microscope, including the mounted specimen on a glass micro slide and coverslip, form an optical train with a central axis that traverses the microscope stand and body. The microscope optical train typically consists of an illuminator (including the light source and collector lens), a substage condenser, specimen, objective, eyepiece, and detector, which is either some form of camera or the observer's eye" (Davidson, 1998–2004, chap. 1, p. 1). Most microscopes were two-dimensional, in other words they had such a small depth of field (plane of focus) that the field was flat, but there were less-common, three-dimensional microscopes (Seyedolali et al., 1994).

Modern compound microscopes are quite sophisticated as compared to the old flea glasses, particularly those microscopes of research grade, and were common components of most school science laboratories. Even toy microscopes and easy-to-make microscopes (Carboni, 2000) surpass the 16th century versions. However, there were some drawbacks to compound microscopes, for example, Davidson noted that "in order to view specimens and record data, microscope operators must assume an unusual but exacting position, with little possibility to move the head or the body. They are often forced to assume an awkward work posture such as the head bent over the eye tubes, the upper part of the body bent forward, the hand reaching high up for a focusing control, or with the wrists bent in an unnatural position" (Davidson, 1998–2004, chap. 2, p. 5). Microscopes required good alignment in the optical train and were sensitive to shock and dust contamination as well, this combined with their relatively high price compared to some more basic lab equipment made them less common in classrooms than some other science equipment.

Digital Microscopy

Some time around the year 2000, digital microscopy was introduced in research and educational applications. Davidson noted that this new technology: "Digitization of a video or electronic image captured through an optical microscope results in a dramatic increase in the ability to enhance features, extract information, or modify the image. When compared to the traditional mechanism of image capture, photomicrography on film, digital imaging and post-acquisition processing enabled a reversible, essentially noise-free modification of the image as an ordered matrix of integers rather than a series of analog variations in color and intensity" (Davidson, 1998–2004, chap. 3, p.1) Initially, the technology was used for digital capture, but it quickly evolved to digital video as well (Davidson, 1998–2004).

As Davidson (1998–2004) pointed out, digital microscopy grew out of the sea change in photographic imaging that came with the development and marketing of relatively inexpensive digital cameras and associated software for image processing and printing (Keith et al., 2003). Apparently, the innovator for digital microscopy was the Intel Corporation, which was making digital microscopes by 2001 (Davidson, 1998–2004). The Intel Corporation partnered with the Mattel Corporation to produce computer microscopes that allowed the user to see an image of what was being viewed with the digital microscope on the computer screen (Davidson, 1998–2004). This microscope, called Digital Blue™ QX3™ Computer Microscope, shown in Appendix A (Figures A1 and A2), allowed the user to view enlarged objects in 16-bit color on a computer screen, store images in a collection, alter images with software, and make time-lapse movies of moving objects at magnifications of 20, 60, and 200 times (Prime Entertainment, 2002). After simple loading of microscope software via a CD, the digital microscope was simply plugged in to the host computer via a universal serial bus (USB) port.

Recognizing the educational value of the digital microscope, the Learning Company produced an online *Teacher's Guide* for the QX3™ digital microscope (Brand & Kalamuk, 1999) and Intel Corporation partnered with the Neo/SCI™ to prepare a curriculum guide for teachers using the QX3™ digital microscope (Neo/SCI, 2001).

Shortly after the Digital Blue QX3™ became popular, an upgraded version, the QX5™, was introduced by the same company and another computer microscope, called the ProScope™ was introduced by Bodelin Technologies. The ProScope™ was a digital microscope (whereas Digital Blue™ was mainly a desk-top microscope that could be modified for hand-held use). Later, Scope-on-a-Rope™ was developed specifically for educational purposes by ScalarScopes, Inc. in collaboration with Louisiana State University (Wighting et al., 2004). In addition, at least three different digital cameras for use with standard, compound light microscopes were introduced for educational purposes by different companies (Wighting et al., 2004).

III. METHODOLOGY

Purpose

The purpose of this study was to examine the effects of the introduction of digital (i.e., computer-based) microscopy on two elementary teachers and their classrooms. Microscopy, or more specifically the use of microscopes to help visualize objects at smaller scales than normal sight, was typically thought of as an integral part of a student's education, mainly in the science classroom. However, because of the high cost of standard light microscope equipment, the delicate nature of standard light microscopes and their required maintenance, the specific training required of teachers using standard light microscopy, and perhaps other cultural factors, using standard light microscopy for most lessons in public schools, such as the school in this study, was limited. This study examined the effects of the introduction of inexpensive, easy-to-use digital microscopes into elementary classrooms where microscopy was never before used or was used less frequently than might be considered desirable.

Qualitative research was chosen as the way to address the research questions of this study because qualitative research allowed the researcher to examine the effects of the introduction of the digital microscope into elementary classrooms by focusing on the whole, rather than breaking the situation down into variables for quantification (Ary et al., 2002). In other words, this research method allowed the researcher to ask questions about the nature and meaning of the two teachers' being in this new situation (van

Manen, 1990). In qualitative research, there are "actual settings as the direct source of data and the researcher is the key instrument" for data collection, the data is descriptive, the analysis is inductive (hypotheses emerge from the data), and there is attention given to participant perspectives (Bogdan & Biklen, 1998).

Overview of Present Study

This was a qualitative research study of two teachers in public school, K–5 classrooms: an elementary enrichment classroom and an elementary art classroom. The main research question was: *How does the introduction of the digital microscope into elementary (K–5) enrichment and art classrooms affect what teachers say and do?*

This qualitative research was conducted mainly by means of five separately recorded interviews of both teachers as well as classroom observation by the researcher (during lessons with students where digital microscopy was used), as explained in more detail below. Subsequently, coded semantic domain analysis of interview data was done by the researcher and these data were used for analysis and interpretation. The site for data collection was an elementary school where both the enrichment and art teachers were employed. The specific methods used in this study were described in this chapter.

Participant Teachers

The two participant teachers were selected because they volunteered to be a part of the initial phase of a university-sponsored, outreach grant project[1] that provided digital microscopes to classrooms at the local school where the participant teachers were

[1] For more information on this grant project, contact the researcher.

located. The participant teachers were told that the researcher (i.e., the author of this study) would be working with the grant's principal investigator (a professor at a local university who had expertise in microscopy) to help introduce digital microscopy into their classrooms and that the researcher would interview and observe them over a period of time. The grant provided their school, and therefore the participant teachers, with new digital microscopes and new laptop computers to use with the digital microscopes. Participant teachers were told that they did not have to participate (i.e., their participation was entirely voluntary). After agreeing, they signed approved, informed consent documents at the outset. Participant teachers were asked to answer the researcher's questions during a series of interviews (for these questions and related documents, see Appendix B) and allow the researcher to observe them using digital microscopy in their classrooms (for classroom descriptions, see Appendix C). All reasonable steps were taken to ensure confidentiality of interview comments, including the use of pseudonyms for participant teachers in notes and in this report.

The outreach grant project began in January, 2004, and continued through January, 2005. However, the researcher observed and interviewed the participant teachers through May, 2006.

The two participant teachers were from different backgrounds, specifically, Teacher E's background was "computers and technology" and Teacher A's background was art. Both teachers had taught all elementary grades (K–5) and each had nineteen years of experience as of January, 2006. The enrichment teacher (pseudonym: Teacher E) was responsible for instruction in kindergarten through fifth grades. The art teacher (pseudonym: Teacher A) was responsible for instruction in grades kindergarten through five at the same elementary school. In the past, Teacher A taught various topics in the scope and sequence of art. Table C1 (Appendix C) showed a comparison of all teacher-provided responses to the researcher's request for background information. In addition, more information on each teacher is contained in Appendix C and the teacher data archived by the researcher is listed in Appendix D.

Participant Teachers' Schools

The public elementary school employing both Teachers E and A was one of five elementary schools that serve the community of 50,000 people in the southeastern United States. A state university was located within this community. The community where the elementary school was located had a relatively high median income compared to the surrounding area. The community also had a relatively high percentage of college-educated parents as compared to surroundings areas and had a reputation for having relatively well-supported, high-quality public schools.

Locations of Study

This study's data were collected in the classrooms of both the enrichment teacher and the art teacher and in the computer laboratory of the elementary school where both the art and enrichment teachers were employed (see Appendix C for classroom and laboratory descriptions). Participant teachers were interviewed in their classrooms and researcher observations of their lessons, including field notes, were made in their classrooms (or in the computer laboratory of the elementary school). Activities of the enrichment class were centered on lessons related to looking at natural materials such as insects, natural processes like crystals growing, and man-made materials with fine details like cloth, currency, and coins (Appendix A, Figures A3 and A4). The art class activities were centered on using the microscope to stimulate students during art lessons, particularly on the Georgia O'Keefe-style of art, wherein small objects were the focus of larger works of art (Appendix A, Figures A5-A7), and on observing the texture of art materials.

The researcher compiled additional figures regarding observed activities of each teacher, their classrooms, and the school's computer laboratory. These images were placed in PowerPoint files E-CD and A-CD, which were located on a compact disc (CD) that is part of Appendix A.

The elementary enrichment classroom of Teacher E was located in the central part of the elementary school. Above the door, there was a sign saying "Welcome." Instead of desks, there were twelve tables, which seated two students each, in the room. There were several computers in the room and much computer information was displayed in wall posters, such as the one titled "Know your Computer." There was a white board across the front of the room and bulletin boards with student information on them. There were bins of supplies and materials for various enrichment labs such as crystals, rocks, and insects. There was a small sink on one side of the room. More information about the teacher's classroom and reference codes for archived data was placed in Appendix C.

The elementary art classroom of Teacher A was located in the first-grade wing of the elementary school. The entrance to the classroom of Teacher A was very inviting because student art work and displays were shown on all walls. Art in Teacher A's classroom reflected the variety of lessons going on there and students' work in progress. There were five tables in the classroom instead of desks. The room contained educational resources including a bookshelf of art books, displays on the elements of art, a large white board, and three desk-top computers. More information about the teacher's classroom and reference codes for archived data were placed in Appendix C.

On some occasions for digital microscopy lessons, both Teachers E and A used the elementary school's computer laboratory room (described in Appendix C). This room consisted of three rows of desks of four tables. Each table had two desk-top computer stations and one student sat at each computer station. Therefore, when digital microscopes were brought into this room, each student could have their own computer and digital microscope. There was a large projection screen at the front of the computer laboratory room where the teacher could display PowerPoint slides or project student-made images during digital microscopy lessons. The room also contained a Sympodium™, which projected to the central big screen at the front of the room.

Workshop and Conferences Attended

As a requirement of participation in the outreach grant project, the researcher, the university scientist (the grant's principal investigator), and the two participant teachers met at workshops held at the local school during one day in January, 2004, and at the local university during one day in January, 2005. This provided additional opportunities to observe the participant teachers and to hear their views and experiences.

In addition, each participant teacher attended at least one national conference during the time period of this study. During this study, Teacher E attended the 2005 American Educational Technology Conference (ATEC) meeting and at that meeting Teacher E discussed using the digital microscope in the classroom. At another conference, Teacher A was present at a 2004 Share-A-Thon sponsored by the National

Science Teachers' Association (NSTA) and participated in a poster session on using digital microscopy in elementary classrooms, including art.

Related Grant Project

As previously noted, an outreach grant project was the starting point for this research. The focus of the grant was to introduce digital microscopy into local classrooms as a way of inexpensively providing computer-based microscope access to elementary and high-school students. In the initial phase, two volunteer teacher participants (Teachers E and A) worked with the professor, who was assisted by the researcher, to implement the digital microscope in the participant teachers' school. The grant project was funded only for one year, and when the grant project ended (January 2005), the researcher continued to collect data from the participant teachers until May, 2006.

Researcher Background

The researcher entered the project as a former elementary school teacher with over twenty-five years of classroom teaching experience. The researcher had a B.S. and M.A. in education and additional graduate course work, mainly in science. The researcher was certified to teach pre-kindergarten through eighth grade in all subjects and grades six through twelve in Earth science. The researcher's teaching experience did not include specifically the use of a digital microscope in the classroom, but did include other classroom experiences with standard light microscopy. The researcher had background experience with the digital microscope through graduate directed studies with the university professor in charge of the grant.

Data Collection and Analysis

Data of the two main types were collected on several occasions over the course of this research (Appendix A, Table A2). These data included five, one- to two-hour interviews and several classroom observations of digital microscope lessons. These interviews consisted of the following: pre-interview 2004; interview after first lesson 2004; post-interview 2004; interview after lessons 2006; and post-interview 2006. Participant teachers were interviewed at the outset of the study (pre-interview 2004) and immediately after their first lessons using the digital microscope (interview after first lesson 2004) and at the end of the first school year (post-interview 2004). These interviews consisted of recorded sessions using prepared questions read by the researcher plus some informal conversations with the teacher participants about their digital microscope experiences. The participant teachers were also interviewed subsequently on their long-term experiences using the digital microscope in the classroom. Subsequent interviews were conducted after their digital microscope lessons in 2006 (interview after lessons 2006) and at the end of the subsequent school year (post-interview 2006). All interviews were digitally recorded (audio only) and these interviews were subsequently manually transcribed for analysis by coding. In addition, the researcher conducted thirteen classroom observations with Teacher E and eighteen classroom observations with Teacher A over the period of the study. A time-line of these interviews and classroom observations was shown in Table D1, which was located in Appendix D.

Recordings and researcher's notes from interviews, researcher's field notes of observations, participant's written survey responses, and researcher's notes on follow-up observations were transcribed into typescript. These typed documents were compiled into two sets of notebooks, one set for each teacher participant. These documents were reviewed thoroughly and then the interviews were marked and coded for semantic domain analysis, which were used to help guide follow up observations and related data collection. Data beyond the interviews were used to help provide context for the teachers' coded remarks obtained in interviews and in making researcher comments upon many of the 'remarks groups' in the next chapter.

The researcher acted as participant observer (Spradley, 1980) during classroom observations of digital microscope lessons. Spradley stated that a participant observer "comes to a social situation with two purposes: (1) to engage in activities appropriate to the situation and (2) to observe the activities, people, and physical aspects of the situation" (Spradley, 1980, p. 54). Over time, the researcher developed a rapport with the participant teachers. The participant teachers knew from the outset the goals and methods of the study.

Specific Research Methods

This study falls in the domain of qualitative research, which means that the aim was to understand phenomena from the perspective of the participants being studied (Ary et al., 2002; Merriam, 1998). Specifically, this qualitative research is akin to grounded theory, which Spradley (1980, p. 15) noted can be applied to the study of "any substantive area of human experience." Grounded theory is grounded in real world observations (data) and the researcher's description of those observations, which distinguishes it from other kinds of qualitative research (Glaser & Strauss, 1967). Ary et al. (2002) remarked that in grounded theory "the researcher has no preconceived ideas about what the theory will be" (p. 448). Ary et al. (2002) went on to say that "in the role of the primary data-gathering instrument, the researcher asks questions about some event, experience, or social phenomenon … he or she collects data through observations and interviews, and then analyzes data by looking for similarities/differences among the participants' responses about the experience" (p. 448). They went on to say that "after forming categories having similar units of meaning, the researcher looks for underlying themes and relationships [related to] the categories" (Ary et al., 2002, p. 448). After constructing tentative hypotheses and further data collection, the researcher inductively "elaborates general theoretical statement[s] well grounded in the data" (Ary et al., 2002, pp. 448–449).

In grounded theory, the "open-ended personal interview is the primary method of data collection" and the researcher "asks questions about what happened to individuals, why it happened, and what it means to them" (Ary et al., 2002, p. 449). In grounded theory research, a distinction is sometimes made between substantive and formal theoretical questions and research studies (Bogdan & Biklin, 1998, p. 160). In this study, basic substantive questions were used (see Appendix B for the questions used) and an attempt was made to link the coded answers to substantive findings after establishing links to educational research literature. This approach was suggested by Bogdan and Biklin (1998, p. 160) as an appropriate approach for a beginning research project. Merriam (1998) noted that substantive questions, such as the ones posed in this study, have "specificity" and a "referent [in] specific, everyday world situations" (p. 15). For example, the main research question posed in this study, *How does the introduction of the digital microscope into elementary (K–5) enrichment and art classrooms affect what teachers say and do?*, had the requisite specificity and 'referent in everyday situations' described by Merriam (1998) and other researchers who have discussed examples of grounded theory research.

The qualitative research methods used in this study incorporated the constant comparative method of data analysis (Glaser & Strauss, 1967; Strauss, 1987; Strauss & Corbin, 1994; Bogdan & Bilkin, 1998). Bogdan and Bilkin (1998) stated that the constant comparative method was “a research design … [that] is like analytic induction in that the formal analysis begins early in the study and is nearly complete by the end of data collection” (p. 66). Merriam (1998, p. 159)) noted that that the constant comparative method is consistent with “concept-building” and is useful for researchers who are not developing global theories. Bogdan and Biklen (1998) discussed the prospect of what they called an emerging theory, which was expected to arise during implementation of the constant comparative method in qualitative research.

In this study, the researcher knew the topic to be researched, but there was no preconception about what effect, digital microscopy might have on the participant teachers and their classrooms (Douglas, 1976; Geertz, 1973; Psathas, 1973). The researcher expected only that digital microscopy likely would have some effect(s) upon the teachers and their classrooms, and focused research efforts on documenting the effect(s).

In qualitative research, some standard procedures are used to confirm developing insights, inferences, or hypotheses and to ensure the trustworthiness of the data gathered. These procedures include triangulation, long-term or repeated observation, multiple methods of data collection, and collaborative or participatory research (Ary et al., 2002; Merriam, 1998). These methods were employed in this study and are explained below.

Triangulation was employed in this study to develop ideas about the effects of the introduction of digital microscopy in elementary classrooms. Various authors (e.g., Guba & Lincoln, 1989; Merriam, 1998; Spradley, 1980) described triangulation somewhat differently, but the common ground was that three perspectives or points of view were used to verify developing insights, inferences, or hypotheses. Spradley (1980) gave these perspectives as examples in a qualitative study: (1) what people said; (2) what people did; and (3) what objects people used. In this study, the triangulation involved the researcher's comparing these three perspectives: (1) the teacher's 2004 pre-interview comments (what they said before introduction of the digital microscope); (2) the teacher's comments in the post-interviews (2004 and 2006); and (3) researcher's observations of the teachers' lessons (2004-2006).

Both long-term or repeated observations and multiple methods of data collection were part of this study. Long-term observations by the researcher were made over the period from spring 2004 to early summer 2006. This study began just before the digital microscopes were introduced into the participant teachers' classrooms. Over the course of this study, digital microscopes were in use in both teacher's classrooms and the lessons involving digital microscopy evolved. Multiple methods of data collection were used, which included multiple interviews with participant teachers, researcher's observations during classroom lessons, and other observations such as meetings and conferences.

Guba and Lincoln (1989) examined basic philosophical questions about qualitative research and contrasted what they called conventional and constructivist paradigms in such research. The three basic questions they addressed were: (1) "What is there that can be known?" (2) "What is the relationship of the knower to the known (or the knowable)?" and (3) "What are the ways of finding out knowledge?" (Guba & Lincoln, 1989, p. 83). These three questions corresponded to ontology, epistemology, and methodology, respectively (Guba & Lincoln, 1989). In contrasting conventional and constructivist belief systems in view of ontology, epistemology, and methodology, Guba and Lincoln (1989, p. 84) noted that (1) conventional ontology holds that "there exists a single reality that is independent of any observer's interest," whereas constructivist ontology "asserts that there are multiple, socially constructed realities;" (2) conventional epistemology held that the observer and the phenomena observed are independent, whereas constructivist epistemology asserted that the "inquirer and the inquired are locked in such a way that the finding of an investigation are the literal creation of the inquiry process;" and (3) conventional methodology would have been "interventionist" whereas constructivist methodology was hermeneutic in that it involved a continuing and iterative analysis and joint construction of conclusions. Guba and Lincoln (1989) pointed out that the conventional paradigm was undergoing a revolution, in the sense of Thomas Kuhn (Kuhn, 1970), and that constructivist thought is the probable successor. This study was constructivist in nature, involving working with teachers and the experience of this phenomenon that directly influencing them.

Limitations of the Study

As noted by Ary et al. (2002), simply because the participant teachers knew they were being observed and for what purpose, they might have behaved differently from the way they usually do, or they may not have been truthful in some ways when answering questions. This observer effect might have affected results in unknown ways in this study, but in order to try to minimize this effect, the teacher participants were allowed to be a part of the collection of the data by being asked for their suggestions and their observations. These were viewed as being valuable to the study and an important component of the data collection. The participant teachers were very interested in the initial digital microscopy grant project and they wanted to continue with the present study (introduction of digital microscopy into elementary classrooms) after the formal grant project ended.

Over the three-year span of collecting data, interviews were conducted on the implementation of the digital microscope into the participant teachers' classrooms. Time was considered carefully as the participants had full schedules so that when an interview was scheduled a certain amount of time was requested. If the amount of time (usually a two-hour block of time was scheduled without interruption) was insufficient, another date to continue the interview was arranged at the participant's convenience. The questions and statements used by the researcher at all times were open-ended.

The interviews were carried out in the same manner, which was as follows: a time was set for each interview with each teacher at a mutually agreed time; the teachers were interviewed separately; and the teachers were provided with a set of agreed questions in writing. The interviewer read the questions and these questions and the participant teachers' answers were recorded. Each teacher was given an opportunity to make any additional comments, which were also collected as data.

Methods in Analysis of Interviews

All interviews were transcribed from the original tape- or digitally recorded interviews. Tape recorded interviews were re-recorded digitally for ease of transcription. These transcriptions included the interviewer's questions, the teacher's answers, and side comments and discussion immediately prior to, during, and after the interviews. All questions were numbered and correlated between interviews, e.g., question number one of the pre-interview was asked of both teachers, so in the transcription of those interviews, question number one was labeled as such. Likewise, all questions in all interviews were worded and numbered the same way. In this way, it was easy to find the same question in each interview and answers could then be compared.

There were three types of interviews: pre-interviews (conducted during 2004 before introduction of the digital microscopes to the classroom); interviews after lessons (conducted after the first lesson using digital microscopes in 2004 and after lessons using the digital microscope ended for the school year in 2006); and post-interviews (conducted during 2004 and 2006 near the end of the school year). All pre- and post-interviews had nearly identical questions. Likewise, both interviews-after-lessons (2004 and 2006) had nearly identical questions, which differed slightly from the pre- and post-interview questions. During the interviews, the participating teachers had before them a typed version of the questions, which were read by the researcher in order to obtain recorded answers. In some instances, the participating teachers' answers required some unscripted secondary questions to elicit a full answer and these ad lib questions and answers were considered part of the scripted question's answer. Also, in some instances, the participating teacher asked for clarification or made other aside comments during the interview and these were considered as part of the question to which those comments were connected in the flow of the conversation.

Once typed and read several times, the transcripts were then coded for semantic domain analysis. This coding process is described in the next section.

Appendix D, the researcher's data inventory, listed the archived interview data of this study. In Appendix D, Table D1 gives the dates of interviews and classroom observations in the form of a time line for each teacher.

Semantic Domain Analysis

The selected qualitative method, semantic domain analysis (Spradley, 1980), was used on interview transcripts as a way of better understanding the participant teachers' behavior in the social situation of their classroom lessons with digital microscopes. According to Spradley, semantic domain analysis consists of an appropriate "cover term," which has a "semantic relationship" to "included terms" that occur in the data (Spradley, 1980, p. 97). Following this method described by Spradley, the researcher chose 'digital microscopy' as an appropriate cover term. Then the researcher examined digital microscopy's semantic relationship (using the phrase 'is a way to') to the 'included terms' that occur in the transcripts. For example, 'digital microscopy is a way to *see better*,' where *see better* was an example quote taken from the interview transcript. By coding the entire transcript (i.e., all answers to all questions posed to the participating teacher), a list of included terms was made for each interview. These included terms, which were lengthy phrases and sentences in some instances, comprised each participating teacher's raw data set.

All included terms (i.e., phrases or statements that finished the sentence, ‘digital microscopy is a way to …’) were shaded in color in the typescript during the initial coding process. Next, the color-shaded comments were arranged in order under the heading of each question and tagged with the question number. Finally, all included terms were tagged as to one of nine selected categories as explained below.

The nine semantic domain categories were selected by the researcher after multiple readings of the interviews and several iterations of organizing the shaded phrases and sentences into coherent groups or categories. The selected categories (and their definitions), in alphabetical order, were: (1) *characteristic* (describes the digital microscope); (2) *comparison* (compares experiences and things seen); (3) *computer* (relates the digital microscope’s use of software, etc.); (4) *connection* (connects to science, mathematics, art, and state and national standards); (5) *knowing* (understands a concept better); (6) *object* (relates to how things look); (7) *seeing* (notices differences under different magnifications); (8) *students* (participant teacher comments about observations of students); and (9) *teacher* (participant teacher comments about self and about other teachers). These categories are explained in more detail in the next chapter, Analysis of Data.

The tagged ‘included terms’ (consisting of a category name, e.g., *connection*, a question number, e.g., 5, plus the abstracted phrase or statement) were then sorted using the word-processing program’s sort function. The end result was a list of tagged ‘included terms’ for each interview of each teacher, which was alphabetized by category and also arranged in number order under each category.

In order to analyze this coded qualitative data about the participating teachers, the tagged and sorted lists of included terms were compiled into a narrative summary, broken down into sequential *remark groups*, for each teacher arranged by category and then by interview under each category. This narrative format, which drew upon pertinent phrases and statements from among many dozens of coded included terms, illustrates both teachers' views about the digital microscope. The narratives for each teacher were analyzed for their literature connections and how they helped answer the research questions posed in this study. These research questions were stated in the first chapter, Nature of Study, and the analysis in the next chapter, Analysis of Data. The narratives, which were broken down into coherent *remark groups* (numbered in sequence) under each interview and category, form the next chapter, Analysis of Data. Literature connections and responses to research questions comprise most of Chapter V, Results and Findings. Appendix D, the researcher's data inventory, lists the archived data pertinent to the semantic domain analysis.

IV. ANALYSIS OF DATA

Overview

For the analysis of data, the researcher used a method of coding interview transcripts (as described by Spradley, 1980, p. 97), in which the researcher chose an appropriate "cover term," which was 'digital microscopy' in this instance, and examined its "semantic relationship" (in this analysis, 'is a way to') to "included terms" (which were words, phrases, or short statements) that occurred in the interview transcripts. Over the course of the five main interviews (pre-interview of 2004, interview after first lesson in 2004, post-interview of 2004, interview after lessons in 2006, and post-interview of 2006), both teachers made remarks that were coded this way into selected categories. These coded remarks are presented below, in separate sections, one for each teacher. For additional discussion of this method, see Chapter III, Methods.

In alphabetical order, the categories for teacher remarks as defined in the Methods chapter, were:

(i) *characteristic* (describes the digital microscope);

(ii) *comparison* (compares experiences and things seen);

(iii) *computer* (relates the digital microscope's use of software, etc.);

(iv) *connection* (connects to science, mathematics, art, and state and national standards);

(v) *knowing* (understands a concept better);

(vi) *object* (relates to how things look);

(vii) *seeing* (notices differences under different magnifications);

(viii) *students* (participant teacher comments about observations of students); and

(ix) *teacher* (participant teacher comments about self and about other teachers).

These categories are explained in more detail in the following paragraphs, which are brief reviews of each semantic domain category and its application. The lower case Roman numeral designation used here (for example, i, ii, iii, …) is used throughout this chapter, Analysis of Data, to identify these nine separate categories.

Characteristic (i) was defined for the purposes of coding interview transcripts as ‘describes the digital microscope.’ This category encompassed the many characteristics of the digital microscope, its software, and the related desk-top computer monitors and laptops. The characteristics of all these digital microscope-related items were compiled into this category.

Comparison (ii) was defined for the purposes of coding interview transcripts as ‘compares experiences and things seen.’ Comparison commonly involved teacher remarks about older methods of conducting the lessons now conducted with digital microscopy and other distinctions such as the view at different magnifications, the view of things that look similar without digital magnification but look differently under the digital microscope.

Computer (iii) was defined for the purposes of coding interview transcripts as ‘relates the digital microscope’s use of software, etc.’ This category focused on the computer alone, and thus was different from the category characteristic. Computer-related aspects such as digital displays, file storage, and other features were included in this category.

Connection (iv) was defined for the purposes of coding interview transcripts as ‘connects to science, mathematics, art, and state and national standards.’ In addition to the subjects listed, others such as writing, language arts, social studies, history, ethics, geometry, and others were mentioned by the teachers.

Knowing (v) was defined for the purposes of coding interview transcripts as ‘understands a concept better.’ Within this category, coded remarks included statements by the teacher about the teacher and especially the students that revealed a better understanding of the topic at hand. For example, observing an object and then coming to a better understanding of the structure or composition of that object.

Object (vi) was defined for the purposes of coding interview transcripts as ‘relates to how things look.’ In this category, the names of many objects observed are listed, but also this category includes how these objects look under the digital microscope. For example, coins are objects, but also in this category the scratches on the coins would be included.

Seeing (vii) was defined for the purposes of coding interview transcripts as ‘notices differences under different magnifications.’ Within this category, coded remarks included statements by the teacher about the teacher and especially about the students that revealed what they noticed under magnification, especially increased magnification. For example, as the close view becomes closer and even closer, what differences are noticed by the observer? Also, what insight is gained by the observer in this process? This category differs from ‘knowing’ in that magnification, especially progressive magnification is involved, and it is about noticing differences more than deeper understandings.

Students (viii), as a category, was defined for the purposes of coding interview transcripts as ‘participant teacher comments about observations of students.’ Within this category are coded remarks of the participant teachers about their students’ remarks, behavior, perceptions, work, and understandings during lessons done using digital microscopy. This category encompasses the teacher remarks that informed the researcher about the student and digital microscopy.

Teacher (ix), as a category, was defined for the purposes of coding interview transcripts as ‘participant teacher comments about themselves and about other teachers.’ Within this category are coded remarks of the participant teachers about the teacher’s own behaviors, perceptions, understandings, reflections, and lessons done using digital microscopy. Also included are the teacher’s comments about other teachers. This category encompasses the teacher remarks that informed the researcher about the teacher and digital microscopy.

The following main sections, which are titled Remarks of Teacher E and Remarks of Teacher A, respectively, have the same organization. Each teacher’s section is divided first by semantic domain category and then by interview (as a subheading under each category). Under each semantic domain category, interviews are organized the same way in each instance: pre-interview 2004, post-interview 2004, post-interview 2006, interview after first lesson 2004, and interview after lessons 2006. At the end of the pre-interview, there is a section called *Researcher summary*. The post-interviews and interviews after lessons are subdivided into one or more *Remarks groups*. The *Remarks groups* contain the pertinent, coded teacher remarks with the researcher's comments for each category. This is followed by a summary of literature connections for the teacher's remarks.

Each *Remarks group* is a short narrative with quoted remarks from the coded breakdown of transcripts (sources: E-NB2, E-NB3, A-NB2, and A-NB3), which are also supplemented by the researcher's comments on the remarks (sources: R-NB2 and R-NB-3). Each *Remarks group* is identified with a numerical code, for example, *E-i-P6 7 of 9* means 'Teacher E, semantic domain category characteristic (i), post-interview 2006, remark group seven out of nine.' The semantic domain categories are coded with lower case Roman numerals as listed in the second paragraph of this chapter.

In the following main sections, Remarks of Teacher E and Remarks of Teacher A, numerical data is also briefly summarized in histograms, which are presented in Appendix A.

Remarks of Teacher E

Teacher E, an elementary (K–5) enrichment classroom teacher, was interviewed using the approved pre/post-interview and after-lesson interview question sets that are reproduced in Appendix B. Relevant background on Teacher E and the teacher's classroom description are located in Appendix C.

The researcher's data archives contain transcript sources and semantic domain coding files for all the quotations in this section. Transcripts with remarks of Teacher E have the following archived sources (in parentheses): pre-interview 2004 (E-NB2-1), post-interview 2004 (E-NB2-2), post-interview 2006 (E-NB2-3), interview after first lesson 2004 (E-NB2-4), and interview after lessons 2006 (E-NB2-5). Files related to the semantic domain coding of teacher remarks have the following archived sources (in parentheses): pre-interview 2004 (E-NB3-1), post-interview 2004 (E-NB3-2), post-interview 2006 (E-NB3-3), interview after first lesson 2004 (E-NB3-4), and interview after lessons 2006 (E-NB3-5). The reference codes mean, for example, E-NB2-1, Teacher E's notebook number 2, tab number 1. See Appendix D for more on these reference codes and an inventory of the researcher' archived data.

Numerical Summary of Remarks Across Semantic Domain Categories

Figures A8 and A9 (Appendix A) are histograms showing the relative number of Teacher E's remark groups across semantic domain categories for pairs of interviews that used the same questions. Figure A8 shows that there were at least a total of six remark groups for Teacher E under each of the nine semantic domain categories when the post-interviews of 2004 and 2006 are combined. For these two interviews, most remark groups are under the categories *students* (31) and *connection* (25). Figure A9 shows that there were at least a total of three remark groups for Teacher E under each of the nine semantic domain categories when the interview after first lesson 2004 and the interview after lessons 2006 are combined. For these two interviews, most remark groups are under the categories *students* (17) and *teacher* (11).

Remarks Organized by Semantic Domain Categories

Category—Characteristic

Pre-interview 2004

About the digital microscope's characteristics, Teacher E noted that the digital microscope would allow students to "get closer" to the image and to "take things apart." The teacher stated that the digital microscope would be more "child friendly" and then remarked “real child friendly.” The teacher noted that the teacher would “not worry that the children are going to break it.” The teacher commented that the digital microscope would “go right where the children need to go.” Teacher E wanted to “put children’s hands on it and get going.” Further, the teacher noted that the digital microscope would allow students to “find and focus an object just [by] holding it.”

About the students’ view of the digital microscope’s characteristics, Teacher E commented that the students would “put it on their shoelaces or if someone is wearing a fancy button.” The teacher thought that the students would use the digital microscope to “complete a science activity and use the microscope to do it.” Further, the teacher anticipated that the digital microscope would allow the students to “get really, really close” to an observed object. The teacher went on to say that the digital microscope would let the students work “with different levels of magnification.” In addition, the teacher noted that this would “give the students options - different ways to look at it,” including “different levels of magnification, including ten, sixty, and two hundred power magnifications.” The teacher predicted that the digital microscope would “assist them in working like scientists.” Further, the teacher thought that the digital microscope may have different results when used by the students when they “find out why… a good light [source] makes a difference.” The teacher also anticipated that the students would “find out why it sometimes lights from the top and sometimes lights from the bottom.”

About the teacher’s view of the digital microscope’s characteristics in lessons, Teacher E noted that the teacher would “do various things that [the students] do not have to have a written activity to go with it.” The teacher noted that in using the digital microscope the teacher could “set up without any trouble.” The teacher anticipated that the students would “start [an activity] with a microscope and a bug.” Finally, the teacher expressed that the teacher would also “enjoy learning about how to use the microscope.”

Researcher summary (characteristic) from pre-interview. In teacher remarks coded in the category *characteristic*, Teacher E spoke about what the teacher expected that the students would see and do using the digital microscope. With regard to the digital microscope and its characteristics, Teacher E spoke about the “get closer” effect, the low cost and “child-friendly” aspects of the digital microscope, its sturdiness, and that the digital microscope was ready to use right away. With regard to digital microscope characteristics and students, Teacher E also speculated on what students might enjoy looking at shoelaces and “fancy buttons”, that different levels of magnification would interest students in science activities, and that the experience might make students feel more scientific. With regard to the digital microscope and the teacher’s perspective, the teacher also expressed that the digital microscope was easy to set up and that learning to use the digital microscope with its specific features was something that the teacher would enjoy.

Post-Interview 2004

Remarks group E-i-P4 1 of 1. Teacher E noted that the digital microscope was “child-friendly and sturdy and then if they handled it or moved it I didn’t feel bad.” The researcher noted that the teacher was more confident because the digital microscope was child–friendly because it was sturdy and that the teacher thought that this characteristic would help when it was handled or moved by the students. Also, Teacher E noted that when students were “picking up the digital blue [microscope] out of base and moving it around and I didn’t worry.” The teacher was confident even when the digital microscope was moved out of its base. Teacher E found that the digital microscope was "so much [more] feasible, so much less expensive, that if the students broke it, we were not out of a lot of cash." The researcher found that the cost of the microscope being inexpensive was important to the teacher. The researcher noted that the affordability and sturdiness of the digital microscope made it child-friendly, but also Teacher E was able to allow students to explore and see in a way that was different than before. Teacher E was confident in the sturdiness and the affordability of the digital microscope and this provided a comfort zone for the teacher who then allowed the students to explore. This opportunity provided the students to then see in a way that was different than before because the students could bring the microscope out of its base and move to where the students wanted to look. The change noted here was in teacher confidence in the physical attributes of the microscope being child-friendly as well as sturdy and inexpensive so that the teacher was not as worried about the cost if the students broke it. This increased confidence and less worry provided an environment for the students to freely use the digital microscope to explore and observe objects which were not possible to be observed using the light microscope. Also, the teacher became informed about what interested the students and what it was that they wanted to observe using the hands-on mode of the microscope. The change here was that the students were able to look at things that interested them which could not have been anticipated by the teacher because the lesson became one driven by student interests and objects provided by the environment at the time, and this in turn informed the teacher about what things interested students.

In these remarks about *characteristics* with regard to the digital microscope, Teacher E described how students actively construct knowledge (Chang et al., 1999).

This new knowledge is based on the students' prior knowledge of what the student thinks an object looks like based on observation without microscopy. As Crowther (1997) noted, when students experience something new (like looking at objects using digital microscopy) they internalize it through their past experiences (not involving microscopy). Teacher E noticed this constructivist pattern from the outset. Lane (1999b) stated that the most effective teaching involved emphasis on active, collaborative learning, which the digital microscope promoted by its physical and computer-based characteristics. Roth (1996b) described how a classroom could be transformed by introducing a new tool that in turn stimulated knowledge diffusion in the classroom. Teacher E noted this effect in commenting on student interest-driven investigation. In discussing teacher change, Richardson (1991) noted the necessary comfort level of teachers and their potential concern with cost. Teacher E's comments relate to these points as well.

Post-interview 2006

Remarks group E-i-P6 1 of 11. Teacher E noted that "I think because they have just a little bit [of freedom], they have that control on moving it around, getting closer, backing up, I think that has something to do with it too." The researcher noted that the teacher pointed out the students' freedom in having the control to move it around, to get it closer, and to back it up. These were important observations made by Teacher E. The students learned "how to change it" through their own manipulation of the digital microscope and objects selected to observe. What had changed here was that the teacher found out that if the students have control over what they want to see, then they have control over what they may discover.

In these remarks about *characteristics* with regard to the digital microscope, Teacher E described how students like to use this tool. Jones et al. (2000) emphasized the concept of tool space, which included tool use, student desire to use tools, and student competition to use tools. Characteristics of the digital microscope lent themselves well to this notion of tool space, which was the center of small group, collaborative learning (Herrenkohl & Gurerra, 1998) in Teacher E's classroom. Roth (1996b) also remarked on the effect of the introduction of tools into an inquiry-based classroom, which was described as promoting knowledge diffusion. Jones et al. (2003) discussed how computer-based microscopy promoted social construction of knowledge, which led to student inquiry.

Remarks group E-i-P6 2 of 11. Teacher E noted that in using the digital microscope students "get a little bit closer to see what you want to [observe], to have … [an] identification idea." This was different from previous experiences without the digital microscope, for example, "when we were doing crystals, I do not think it would have made any impression on them at all … I have grown crystals where you did, over several days, and they mounded up on the string." Teacher E noted that the digital microscope allowed students to get closer to see what was happening, in this instance, crystals growing. The results were different than growing crystals over several days and seeing the crystals mound on the string. The researcher noted, that getting a little bit closer as the crystals were forming allowed the students to see the crystals growing and made an impression on the students. These remarks showed a change in what the teacher observed about what the students did or said when they worked on the crystal-growing lesson. The researcher noted that the teacher remarked that working with crystals this year using the digital microscope made an impression on the students in contrast to the past lessons where the students watched crystals grow over several days while the crystals mounded up on a string. The difference that this teacher observed was the ability for the students to get closer and actually be observers participating in the watching of the crystal growth process in real time. The researcher noted that the students learned how to manipulate the digital microscope, and the teacher was able to observe what the students did as they looked at the objects under magnification.

In addition, Teacher E noted that “they have that control on moving it around, getting closer, [and] backing up, I think that has something to do with it too.” The way the students manipulated the digital microscope, informed the teacher about what students do when they are using the digital microscope and, in this instance, led the teacher to interpret that the students were impressed by what they were observing in comparison to previous lessons where they observed crystals growing over a period of several days.

In these remarks about *characteristics* with regard to the digital microscope, Teacher E refers to many student interactions with the digital microscope. Rahm et al. (2003) describe authentic science as being caused by interactions, including those between students and teacher during science activities. Bouillion and Gomez (2003) note that activities that students can directly relate to such as the crystal growth mentioned here are the most effective authentic science mechanisms. Roth (1994; 1999) discusses the importance of student interactions with materials and each other in the emergence of a student discourse that leads to more conceptual understanding of topics being studied. Roth (1996b) noted how knowledge diffusion occurs in a classroom where a new tool is introduced and students are allowed to use it freely during a specific activity. Teacher E's comments relate directly to student discourse, knowledge diffusion, and tool use.

Remarks group E-i-P6 3 of 11. Teacher E noted that using the digital microscope was "not as sensitive as far as the bumping, to some degree." This referred to looking at the object through the digital microscope where "they can get it on the screen; everybody sees it at once. It is not you see it, I see it, they see it…it is not one at a time." Teacher E saw a change using the digital microscope where "everybody could see it at once" instead of "you see it, they see it, it is not one at a time." The researcher noted that the change is in not having to worry about the possibility of the students bumping into the microscope and changing what is viewed. The teacher was more confident that everybody sees the image at once, and it is preferred to taking turns and viewing the object in the traditional microscope. Teacher E noted the digital microscopes "gave a broader view."

In these remarks about *characteristics* with regard to the digital microscope, Teacher E acted as a participant observer of student work and interactions. The teacher was able to observe a constructivist classroom environment, which revolved around hands-on activities that did not have a recipe formula for success (Crowther, 1997; MacKenzie, 2001). In this setting, the digital microscope was the central tool (Jones et al., 2000). Roth (1996b) noted how a new tool and student adoption of that tool can wholly transform the setting of learning. Teacher E noted how the digital microscope tool transformed the inquiry, because all could see what everyone was finding. Consistent with best practices in an inquiry classroom (Liem, 1987), the teacher acted as a participant observer with the students during inquiry.

Remarks group E-i-P6 4 of 11. Teacher E noted that in using the digital microscopes you are “able to have the microscopes in a cabinet, but the images are still on the computer.” This would allow “for more time in preparation and as long as you are able to access the computer you could still do a lesson.” The researcher noted that this showed a change in being able to use the digital microscope image through the data file even when the digital microscope was not being used and that was not possible before using the light microscope.

Also, Teacher E noted that you “can still make a movie of it or take a picture of it… [however] if it was a stand alone, standard [light] microscope, [then] after you look at it [the object] and move it, there was no recording.” In other words, the standard microscope did not allow for video to be made. Teacher E noted that “you could label it and you could use it in several mediums, in PowerPoint or Word or just print out the picture.” This was another benefit of the digital microscope. Teacher E remarked that you could “use the program and do ‘set B’ or the second half of your lesson without dragging the machines out again…the images you have already captured, you can work with them.” The researcher noted that Teacher E was very specific about the benefits of the digital microscope and connection to the computer. The change noted was that the microscope capabilities were enhanced by the computer components which was not possible with the light microscope used in previous lessons.

In addition, Teacher E noted that the “lesson used with the digital microscope can be used and changed as the images that are captured by the digital microscope now can be enhanced through the computer functions” of the digital microscope including image labeling, making a movie, linking to PowerPoint presentations, being useful for preparing

Word documents, and archiving for use in another lesson. The researcher noted that the teacher discussed many options that were available using the digital microscope especially the connection to the computer functions and this showed a change in the effectiveness of the digital microscope from this teacher's experience since the implementation of the digital microscope into the classroom.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E noted how the students developed connections from one medium to another. This is related to the metacognitive process described by White and Fredrickson (1998) and Pearce (1999), wherein one inquiry cycle is followed by reflection and then further inquiry by the student. Teacher E noted the genuine student inquiry as key to building understanding and competence, which is discussed by Tinker (1997) as a good reason for learning partnerships. Roth and Welzel (2001) discussed how graphic representations have an important cognitive function, specifically scaffolding of students' development of complex explanations when they do not yet have much scientific language. Roth and McGinn (1998) referred to these graphic representations as inscriptions and they discussed how inscriptions focus attention and coordinate and constrain activities and conversations. Teacher E brought out similar effects in describing digital microscopy in this instance.

Remarks group E-i-P6 5 of 11. Teacher E wanted to "do more and more to support what the teachers are doing in the classroom, not to make it a separate whole issue, but for it to kind of go along." This showed a change in lesson plans and learning to incorporate digital microscope technology with other teachers and their classroom curriculum. The researcher noted that this showed change in inter-disciplinary or intra-disciplinary connections to other teachers and also their students. Teacher E wanted to be able to integrate the digital technology by supporting what the teachers are doing in the classroom. Teacher E commented that for "it to kind of go along [with other lessons]." The researcher noted that there was a scaffolding effect by the introduction of the digital microscope in the enrichment classroom, and the teacher now wanted to do more and support what is happening in the classroom also. The researcher noted change in collaboration and communication between teachers and lesson enhancement.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E mentioned collaboration with other teachers. Such collaboration is a natural outgrowth of classroom scientific inquiry (Lawless and Rock, 1998). Richardson (1990; 1991) noted teacher collaboration is a characteristic of teacher change within cultural norms of the school. Roth and Welzel (2001), Bouillion and Gomez (2001), and Roth (2003) note how scaffolding of new learning upon earlier knowledge is an important aspect of new learning.

Remarks group E-i-P6 6 of 11. Teacher E noted that the digital microscope "wowed them!!" The researcher notes that the students were especially enthusiastic about the digital microscope and this is a remarkable statement.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E represents the student's voices saying things like "wow." This "wow-factor" for students commonly occurs when their world view is challenged by something they see (Kusnick, 2002). The digital microscope challenges their world view because few of them have seen the world in this way before. Roth (1999) suggested that utterances, such as 'wow,' are more the property of the group rather than individuals. In other words, individual students utter ‘wow’ but in so doing they are trying to involve the group in a new discovery or understanding. Roth (1999) saw these key utterances as part of a process of shared discourse with classroom communities of practice.

Remarks group E-i-P6 7 of 11. Teacher E noted that the students “liked that it [the image] shined up on the computer.” The researcher noted that the teacher was very specific about what the students liked in this aspect of the digital microscope. Teacher E noted that the digital microscope is “cheap enough so that if something happened, it was okay but they could handle it, pick it up, maneuver it.” Teacher E mentioned again that because the digital microscope was inexpensive allowed the teacher to let the students “handle it, pick it up, maneuver it.” The researcher noted that it was important to the teacher to let the students handle it and pick it up which was possible because the teacher did not have to worry that the students were handling something that was expensive, may break, and then need to be replaced. The researcher noted that because the teacher did not have to worry about this aspect of handling the digital microscope, the teacher was able to say that the students could handle and pick up and maneuver the object. Once the teacher felt safe to let the students handle the digital microscope, the teacher was able to let the students explore with it. The researcher noted the change was in the teacher feeling safe to let the students explore with a new instrument.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E speaks of students in control at the microscope. Active construction of student inquiry is a key factor in highly effective student learning according to authors such as Crowther (1997), Chang et al. (1999), and others. In studying teacher change and the culture of schools, Richardson (1991) noted the importance of cost considerations in teachers' willingness to go along with some types of curricular change. In this instance, the worry is over cost of breakage, which is important to teachers in this study and clearly is on their minds.

Remarks group E-i-P6 8 of 11. Teacher E noted that the digital microscope will "be child-friendly-usable like that." The researcher noted that the teacher found that it was important that the digital microscope was child friendly and this was a characteristic that the teacher had anticipated that would happen. In addition, Teacher E noted that students "liked the availability to use it with other programs … so that was their favorite stuff." The researcher noted that the teacher, by using the digital microscope, found out something about the students and what interested them the most. In this case, it was that the students could use other computer programs that they already knew that were also available through the digital microscope computer programs. Teacher E noted that students "learn a lot of computer skills for sure … I mean just learning to click on certain areas, or learning to … the computer aspect of it … saving it, file management and things like that." The researcher noted that Teacher E was interested in the computer aspect of the digital microscope and saw the connection to programs that the students were familiar with; but also the digital microscope helped develop computer skills that the teacher mentioned. This shows a change in what this teacher noted in the pre-interview 2004. Teacher E mentioned more about the function of the digital microscope as a microscope and now in the post-2006 interview mentions more about the how the digital microscope enhanced and developed the students' computer skills through the digital microscope's computer technology.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E mentioned the child-friendly aspects of the microscope and the students' building on prior knowledge. This relates to the work of Seiler et al. (2001), who found that almost all students readily adapt to new technology if given the opportunity and encouragement to do so. Richardson (1991) noted the importance of cost considerations in teachers' willingness to go along with some types of curricular change. Regarding building on prior knowledge, this is a view directly from constructivist theory, which says that prior knowledge upon which to build new knowledge (Crowther, 1997; Chang et al., 1999; Lovrich, 2004). Roth and Welzel (2001) and Bouillion and Gomez (2001) also take this view of scaffolding in student cognitive development in general and hands-on lessons in particular.

Remarks group E-i-P6 9 of 11. Teacher E remarked that there were few problems using the digital microscope. For example, Teacher E noted that the students could "trouble-shoot on it … we did not have any major problems as far as it not doing what we wanted it to do…sometimes it just that they were not doing something as small as not changing the magnification or changing the focus knobs." The researcher noted that the teacher did not find any significant problems while implementing the digital microscope and just mentions the students may have had a problem with the focus or magnification while using it. In addition, Teacher E noted that they wanted to "find more ways to plug it in, and then coming up with some [new activities because the students] would have seen what we have done this year, last year, the year before." The researcher noted that Teacher E wanted to add more ways to use the digital microscope in other lessons and then compare them with lessons using the digital microscope in the past. Also, the researcher noted that the teacher was interested in adding more lessons using the digital microscope, which shows a change in curriculum. Further, the teacher wanted to compare these lessons with what had been done in the past several years using the digital microscope. The researcher noted that this teacher was concerned with curriculum development as well as curriculum review which shows that the implementing of the digital microscope caused a change in the current curriculum as well as being considered to be included in the future curriculum.

Also, Teacher E also remarked that it would be good “coming up with certain things that we could use and having samples on hand, certain things that you could draw back to and just having a bank of items to be used that work well.” The teacher was more specific besides finding ways to include digital microscopy in future lessons but also to have specific items on hand to use in the lessons. The teacher mentioned that it would be good to have “a bank of items to be used that work well.” The teacher was building on what was learned that could be used in lessons that were successful and shows that using the digital microscope helped in the planning of more specific things to include that would make future lessons successful. The change the researcher noted in this instance, is in curriculum development as well as consideration for the more specific individual lesson plan and items needed based on past success using the digital microscope.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E at times addresses curriculum change. Such change motivated by authentic scientific learning and active inquiry are supported by major educational reports including AAAS (1989), AAAS (1993), and Lane (1999b), among others. Richardson (1990; 1991) found that curriculum change may be driven by outside factors, but that all change comes primarily from within each teacher. Richardson (1990; 1991) argued that teacher change is driven in large part by the teachers' underlying beliefs. So, it is reasonable to assume that Teacher E had at least an "experimental belief" (Senger, 1999, p. 209) that this new kind of microscopy would be beneficial.

Remarks group E-i-P6 10 of 11. Teacher E recommended "getting a few more [digital microscopes] … [besides the] twenty computers in here … [then] you could have two homerooms in [this room] working, two kids on a unit." Teacher E projected that if they could get more microscopes in addition to the twenty that they already have then two homerooms could be working together with two students to a unit. The teacher was also considering the room set-up with pairing up not only students but several homeroom classes working together using the computer. The teacher was planning how additional microscopes would make this possible and that more students could have the experience using the digital microscope. The change noted here was in budgeting and planning for expansion of the implementation of the digital microscope while considering how the purchase of more would affect the classroom set-up. The teacher wanted more microscopes and mentions specifically to have two students to a unit.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E notes how the digital microscope affects planning and classroom set up. This effect is predictable, according to Marek (2002) and Harnik and Ross (2003) as teachers try to achieve standards using new technology. Richardson (1990; 1991) also touches on these aspects of teacher change in situations where the teacher change is driven more by teacher interest rather than external decision making. Brand and Kalamuk (1999) discussed how the digital microscope specifically meets numerous national standards, and they related specific inquiry activities with digital microscopy to the standards guide of the National Research Council (1996).

Remarks group E-i-P6 11 of 11. Teacher E noted the digital microscope helped students “notice more things.” The researcher noted that the teacher mentions the students noticing more things but the teacher is not clear what is meant by “things.” Teacher E also noted that students “learn to put it [the object] in the middle of the platform, focus it on the stage, [and] then go in a little tighter [closer].” The researcher noted that the teacher became more specific about what students do to see an object more closely. The teacher mentioned that the students specifically learned to place the object in the middle of the platform, focus it on the stage, and then go in a little tighter. The researcher noted the teacher’s use of the scientific names for the parts of the microscope which was not mentioned in previous interviews. This showed a change in the teacher’s scientific knowledge of digital microscopy. The description of what a student did was an account of what the teacher observed while students looked at an object. The researcher noted that the teacher remarked ‘then go in a little tighter.’ This also showed that the teacher had knowledge of what was done by saying ‘tighter.’ The teacher’s knowledge of how to focus helped in the observation of what students do to look at an object under the digital microscope. The researcher noted that experiences of both the teacher and the student using the digital microscope helped in the way the teacher observed and described what students do when looking at an object using the digital microscope. The change noted here would be in the teacher’s experience directly influencing the ability to instruct and then observe students using the digital microscope. Another change noted was that the teacher found the students to have control of what they wanted to see and have control of what they may discover.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E notes changes in the teacher's approach as well as the students.' Donovan et al. (1998) noted potential changes, including some described by Teacher E (for example, students noticing more things under the microscope and students working more effectively with focusing the microscope), in discussing changes in pedagogy in the classroom when constructivist activities are used. Richardson (1990) noted that teacher change, such as that noted here, is largely a function of the individual teacher's underlying beliefs, attitudes, goals, and knowledge. The teacher becomes a teacher learner when the change is controlled by the teacher. Richardson (1990; 1991) noted that teachers take cues from their school environment, but that changes such as those noted here come from the teacher's personal biography.

Interview after First Lesson 2004

Remarks group E-i-A4 1 of 1. Teacher E noted that the students were involved "just getting to know how it worked" and "just getting to know the parts of the microscope." Teacher E observed that the students were enthralled, saying "but for [the students)] to sit there [at the microscope] and turn the dial and roll it and change it, maneuver it and manipulate it … and [see] that is how it works." The researcher noted that Teacher E described what the students did using the microscope. This shows a change in what the teacher learned about how students got to know how the digital microscope works. The teacher noted that the digital microscope was able to "focus quickly," which was valuable for students.

In these remarks about *characteristics* with regard to the digital microscope, Teacher E again mentions the child-friendly aspects, which were noted in the teacher's pre-interview 2004 comments. Richardson (1990; 1991) remarked that teachers' willingness to make curricular change on different levels is dependent in part upon practicality and situational effects. These things may be tied directly to how well the teacher and students accept new tools and their inherent friendliness to new users.

Interview after Lessons 2006

Remarks group E-i-A6 1 of 3. Teacher E found that digital microscopy is a way to "make sure that everything is so safe and secure … this was so much easier … because if something happens you are not down thousands of dollars." The teacher noted that it was easier to make sure the microscopes were safe and secure and even if something happened you would not be out so much money. The change here was in the teacher's confidence and how the teacher related safety with confidence and cost.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E notes often the cost factor and sturdiness of the equipment. The teacher is obviously concerned about cost of replacement and possible student damage. The cost of equipment is not a common focus of most literature, but some inexpensive projects using durable equipment have been described, including the 'science boxes' program discussed by Cannon (2000) in which inexpensive equipment was put to heavy classroom use via a mobile lab. Richardson (1991) noted the importance of cost considerations in teachers' willingness to go along with some types of curricular change.

Remarks group E-i-A6 2 of 3. Teacher E stated that in using the digital microscope you can "save different images, then you can always come back to it." This was a positive attribute of the digital microscope and its ability to store images. The light microscope could not do this. The teacher found this to be important which showed a change here in the digital microscope's ability to save different images which then could be retrieved later and used in other lessons.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E spoke about the computer functions related to imagery. Davidson (1998-2004) discussed how these functions evolved out of inexpensive technology coming from the digital photography revolution. As Seiler et al. (2001) pointed out using such technology in the classroom enhances students' sense of accomplishment and is a way of earning classroom respect from other students. The imagery may also help students develop mental models of the things they study (Greca & Moreira, 2000). Roth and Welzel (2001) and Bouillion and Gomez (2001) also take this view of scaffolding in student cognitive development in general and hands-on lessons in particular.

Remarks group E-i-A6 3 of 3. Teacher E discovered that digital microscopy is a way to "get to know how to focus, and what does the focus mean and do I need to be up at 200 times the magnification or do I not … 60 may be better … because some of them always wanted to go to the higher magnification thinking 200 that's good … that's better ... 10's good but 200's better … but they would learn that if "I get [too] close I really can't see anything." The change noted here was in teacher knowledge of the digital microscope and magnification and that Teacher E uses terminology that was much more specific to digital microscopy.

In teacher remarks about *characteristics* with regard to the digital microscope, Teacher E spoke about problem solving approaches that the students took regarding magnification levels, including discrepant events that led to student confusion and dilemma. Roth (1999) discussed this effect, which he terms phenomenological understanding. This is the type of understanding that students gain by the trial and error of hands-on learning. The students might have come to a conceptual understanding by reading about the digital microscope's magnification levels, but they acquired a deeper understanding by using the microscope themselves. Liem (1987) and Appleton (1996) discussed the constructivist aspects of learning from discrepant events. They advocated inquiry-based lessons built on discrepant events; however the discrepant events in this instance emerged unexpectedly from the lesson. Teacher E noted how the students were faced with the cognitive conflict of selecting magnifications. The students used social interaction to resolve their questions about what was happening.

Category – Comparison

Pre-interview 2004

In very limited remarks, Teacher E noted that the digital microscope would "give different ways to look at [things]" and that the digital microscope would allow the students "to do some comparisons."

Post-interview 2004

Remarks group E-ii-P4 1 of 1. Teacher E expressed that students "liked looking at something that looks kind of plain and then you get closer to it and say 'oh no, look' – there is something different there." The teacher noted that "then when you move that into the digital it is so much bigger." The researcher observed how the teacher was informed when the students remarked 'oh no, look' that they were interested in an object that at first looked plain but as they got closer they found something different. The change here was in how the teacher learned about the things that interested students according to what students do or say when they look at objects using the digital microscope.

In teacher remarks about *comparison* with regard to the digital microscope, Teacher E spoke about the students' reactions to things that looked plain to the eye, but had remarkable hidden features revealed by the digital microscope. Roth (1999) noted the importance of student utterances in the emergence of discourse in science classroom activities. Roth et al. (1999) viewed student utterances as being of great importance in the emergence of communities of practice in the science classroom. Such communities of practice are essential to the collective development of knowledge in the classroom. Such knowledge diffusion, noted by Roth (1996b) may be transformed by the introduction of a new tool, in this instance, the digital microscope.

Post-interview 2006

Remarks group E-ii-P6 1 of 5. Teacher E noted that the students "take a movie and then to look at it, and play it back, and then to notice the things that they really did not see when they watched it with their eye … but then they could play it and play it and play it … and they are like, 'oh, but look,' he is doing this or that." The researcher noted how the teacher observed what students do and say when they look at the image and then play it back. Teacher E compared it to observing with just the eye. Students played back a movie and then "say 'oh, but look,' he is doing this or that.'" The change that occurred here was how the teacher learned about what interested the students by what they do or say. This was different than what the teacher had learned in 2004. The students now have learned to use the functions of the digital microscope and then the teacher is informed by what they look at and then play back. The teacher found that the students did not pick up with their eye originally but after playing it back, which is now possible with the digital microscope, they are able to observe different things that they had missed. The researcher noted that the change in video technology of the digital microscope led the students to have better observation skills and this informed the teacher about what interested students when using this technology.

In teacher remarks about *comparison* with regard to the digital microscope, Teacher E spoke about the students' reactions to things that they missed at first, but now see because of the video capability of the digital microscope. Jones et al. (2003) studied the behavior of students who used remotely operated microscopes and they observed that social construction of knowledge is enhanced when students gather around a computer screen during microscopy sessions. Roth et al. (1999) spoke of focal artifacts, which are things to study and recapitulate experiences within classroom groups. The video here takes the place of the focal artifact and in so doing becomes its own transforming tool (Roth, 1996b).

Remarks group E-ii-P6 2 of 5. Teacher E stated that digital microscopy "solved a lot of [problems so that] you could go back to it … you could have a lesson and when we used the microscopes we would set them up and after that day, put them up, and they were gone … we could not refer back to them." Teacher E compared the digital microscope to the light microscope and the advantages of being able to refer back to the images that were seen with the digital microscope and not with the light microscope. The researcher noted that the teacher's lesson plans changed because the digital and light microscopes were different in their capabilities. The researcher also noted that the teacher was aware of the importance of prior learning and being able to refer back to previous images that were stored on the computer.

In teacher remarks about *comparison* with regard to the digital microscope, Teacher E spoke about the importance of being able to look back at stored images from previous laboratory activities. Roth and McGinn (1998) discussed the importance of inscriptions, or visual representations of nature, as being of critical importance to the inquiry classroom. Such inscriptions, or video images in this instance, are a means of engaging others in thought and conversation as part of the authentic learning process. Roth and Welzel (2001) mentioned such representations as scaffolds to students' cognitive development. It is easy to see how these archived images could be scaffolds to student learning when the students remarked that they learned new things from viewing these images.

Remarks group E-ii-P6 3 of 5. Teacher E discussed being able to help students while focusing on an object using the digital microscope. The teacher noted the advantage of seeing the image on the computer monitor instead of checking the objects through the eyepiece of a standard microscope. Teacher E remarked "it was not as easy with the standard microscope." Teacher E also asked the students about their understanding. The teacher mentioned "watching – 'okay, your computer is not showing me this' … do you understand why?" The teacher remarked that "it is really fuzzy … because … if they were looking at a standard microscope, and they were looking at (something), you would not know if it was fuzzy to them or not or if they truly had it in focus." The teacher added "but I can look across the way and say 'you really need to focus it some more' … because they may be saying 'it is focused to me' … they would say, ‘well, I can’t see it’ or ‘this isn’t really good’ … well, why do you think it is not?” About the activity on paper currency, the teacher remarked “for them to (ask about currency) why does mine have a K and his has an R and hers has a – you know – different letters [is interesting].” The researcher noted that the change here was in how the teacher found out not only from what the students say but also by what the students showed on their monitors. Further, the researcher noted that this sort of thing was not possible with the standard microscope. The teacher was able to ask specific questions about what the students chose to put on the monitor. Using the light microscope the teacher was not able to really know what the students were looking at and if the object was out of focus. In this instance, change occurred in the technology of the digital microscope and that improved how students were able to view objects under magnification. This in turn helped the teacher and other students to be a part in this observation. Teacher E stated that students were wondering about ‘how something happened’ and ‘why did this change.’ Students are seeking answers. Teacher E says that with the digital microscope the students are asking questions that can be answered in a different way than before. In the past, students had problems in understanding why something was fuzzy and the teacher would not know if it was fuzzy to them or not – or if they had it in focus. Now the teacher could look across the room and converse with the student about the image that was on his or her screen. The questions changed from the questions the students asked with the standard microscope (‘I can’t see it’ or ‘this isn’t really good’) to more why-type questions such as ‘why do you think it is not?’ or ‘why does mine have a K?’ and wondering why or how this happened or why did they change this? These type questions are more inquiry based. Much of this came out of remarks about the currency lesson conducted by Teacher E.

In teacher remarks about *comparison* with regard to the digital microscope, Teacher E spoke about the importance of interaction and dialogue in student learning during digital microscopy. Rahm et al. (2003) wrote about authentic science as an emergent property of partnerships and collaborations. In this instance, the partnership is between the teacher and the student group and the collaboration is within the student group and between it and the teacher. Roth (1994) took the view that students will communicate their findings in an inquiry-based classroom in much the same way as scientists in their work environments. Roth (1994) observed that efficient communication occurred when the student group had access to the representational device (here, the digital microscope) and the device spurred authentic dialogue and argumentation.

Remarks group E-ii-P6 4 of 5. Teacher E stated “imagine what they can do, if they have their own laptop that they will have access – twenty-four, seven … and it will be wireless in the media center and certain areas of the building it will have wireless capabilities … you know, *wow!*” The researcher noted how much Teacher E was excited about this idea. The teacher speculates on what the possibilities could be for the students being able to use the lap top computer and its wireless access. It was significant that Teacher E stated ‘wow’ to this possibility and showed that the teacher was impressed by the possibilities that the digital microscope could have in a wireless network and in each student having their own laptop. This showed a change in what the teacher was able to envision about the direction the digital microscope can take.

In teacher remarks about *comparison* with regard to the digital microscope, Teacher E spoke about what the teacher imagines could come in the future using digital microscopy and wireless connections with student laptops. Also, the teacher expressed excitement and vision about the lessons using words like '*imagine what they can do*' and '*you know, wow!*' The teacher's mention of future connections for digital microscopy, as compared to the present situation, suggests that the teacher has thought about these possible future applications and is open to them. In discussing teacher change, Richardson (1990; 1991) noted that teachers are open to change in accord with their personal biographies, in other words their backgrounds and interests. Teacher E has a computer background, so this kind of future vision is understandable in this regard. Liem (1987) spoke about the critical role of teacher enthusiasm in the classroom, which Teacher E expressed here. Liem noted "although you cannot teach (enthusiasm) to students, they can catch it from you" (Liem, 1987, p. 20).

Remarks group E-ii-P6 5 of 5. Teacher E spoke about comparing images if one could "pipe some of their images out there … and that way you feel like you are backing up what you are doing in class." The teacher went on to say "and the kids … it expands (on what they are doing), they could see it and work with it at home at that point… because they could download the image and write their story about the day we made a crystal or the day we found the (special thing), or whatever." Teacher E revealed a philosophy of what was good reinforcement for student learning, which was taking place in class. The teacher expressed the view that by having a means of communication to the students at home, they could see images and then work at home with things they saw during the day. The teacher envisioned the capability of images being stored for homework lessons, because the image could be downloaded at home and the students could write a story about ‘the day they made crystals.’ The change in this case was in lesson planning, home-school communication, and further student learning. The researcher noted that what the teacher stated here revealed that the teacher envisioned the digital microscope providing extension of in-school activities. This showed change in the way the digital microscope provided future opportunity for learning in the classroom, in other subject areas, at home, with other students, and with family.

In teacher remarks about *comparison* with regard to the digital microscope, Teacher E spoke about what the teacher saw as a possible comparison between school and home learning and the potential for student writing projects done at home as a result of digital microscope lessons at school. Richardson (1990; 1991) noted that teachers envision change in accord with their personal biographies, in other words their backgrounds and interests. Teacher E had a computer background, so perhaps this teacher’s vision of computer connectivity at home is to be expected. Including writing in the lessons was a well-founded holistic, constructivist teaching principle. The same communication goal was manifested in the digital imagery from the digital microscope enrichment lessons.

Interview after First Lesson 2004

Remarks group E-ii-A4 1 of 3. Teacher E noted that for one student, digital microscopy is a way “[to make] the connection [to] something he liked – being outdoors.” Teacher E found that digital microscopy is a way for students “[to] see you [the teacher] excited and they then get excited ... it is contagious.” The researcher noted that this was important because it revealed what the teacher did when the students get excited about what they are doing. The change here was the teacher's discovery about what happens when the teacher and the students became excited about the lesson.

In teacher remarks about *comparison* with regard to the digital microscope, Teacher E spoke about what excites the teacher about digital microscopy compared to what excites students. A teacher becoming excited about student activities may be viewed as a type of teacher change if it was not present before. The teacher observed a new level of excitement as a result of the students' excitement. Richardson (1990; 1991) noted how teacher change is very commonly an effect of the teacher's predisposition to such change. Liem (1987) wrote about teacher excitement and its importance to lessons on inquiry. Teacher E remarked on this point and expressed that excitement was conveyed to students and vice versa.

Remarks group E-ii-A4 2 of 3. Teacher E found that digital microscopy was a way to "attack the next problem with something they already know." The researcher noted that the teacher was saying that there were foundations that will help the student understand. The teacher related to a personal philosophy of students' building on formerly acquired knowledge. In addition, Teacher E remarked "to have to reach down and maneuver something was different [not autofocus like an autofocus camera]." The comparison to the camera was made by the teacher and the students alike. Teacher E compared digital technology to the autofocus on a camera and that focusing the image using the digital microscope was different than what the students were familiar with – a camera that focuses for the user. The teacher related to something with which the students were familiar. This comparison helped to instruct the students about focusing using the digital microscope.

In teacher remarks about *comparison* with regard to the digital microscope, Teacher E spoke about students using prior knowledge to approach new problems in digital microscopy. Donovan et al. (1998) and Lovrich (2004) noted that teachers must draw out and work with pre-existing understandings on the part of the students in order to effectively teach. Teacher E applied this principle when asking students to 'attack the next problem with something they already know.' The same authors just cited reported that teachers can more effectively teach if they work with students' pre-existing understandings. Comparing the digital camera and digital microscope, in this instance, was a useful teaching technique. Crowther (1997) defined constructivism as internalizing something new through our past experiences. Teacher E remarked on something akin to this type of constructivism in the enrichment classroom.

Remarks group E-ii-A4 3 of 3. Teacher E compared the digital microscope to the eye "to find something that they could see that they cannot see with their own eye themselves." Further, the teacher remarked "[to see when] you absolutely cannot see it with your eye." Teacher E compared the image taken by the digital microscope in order to "[to] find things … [that] look a lot better." The researcher noted that the comparison to the eye and using the digital microscope to see things that the eye can not see.

In teacher remarks about *comparison* with regard to the digital microscope, Teacher E spoke about what interested students in remarking about the unaided eye versus the digital microscope. In making comparisons to the unaided eye, Teacher E expressed what Roth (2003) called scaffolding to the student's cognitive development. This process, which is rooted in graphic representations made by students, was an essential part of science classroom learning, according to Roth (2003).

Interview after Lessons 2006

Remarks group E-ii-A6 1 of 1. Teacher E remarked that the digital microscope was a way to help us with the curriculum: "instead of changing [the curriculum] … [I] was able to combine [topics] … we have … technology curriculum now and we have science curriculum and we have art curriculum." The teacher added "and there were times that there were all three of those … being taught at the same time." The teacher spoke also about the necessity of combining lessons to cross the curriculum. The change here was by implementing the digital microscope a way was found to have a lesson that crossed into several areas of the curriculum that are usually taught separately. In earlier comments, Teacher E remarked that the digital microscope gave students a new way to look at things and noted that students began noticing how different magnified objects look when viewed with the digital microscope. Later, Teacher E made more comments that reflected changing views on comparisons using the digital microscope. These changes included the view that students have now learned how to use the digital video aspects of the microscope and this technology improves student observational skills, that comparisons have become part of the lesson using the digital microscope, that digital microscope technology allows for more complex comparisons inside and outside of class, and that the nature of student questions were more complex than before because of the comparisons that students can make using the digital microscope.

In teacher remarks about *comparison* with regard to the digital microscope, Teacher E spoke about inter- and intra-disciplinary connections through digital microscopy and compared pre- and post-digital microscopy curricula. Teacher E noted the interconnectedness of science and art in digital microscopy and how this related to cross-curriculum relationships. Wright (2000) discussed the similarities of science and arts with regard to study of natural things, saying that both art and science dealt with graphics and the deeper meaning of graphics. Teacher E alluded to this also in the remarks above.

Category – Computer

Pre-interview 2004

About the digital microscope's computer aspects with regard to a lesson, Teacher E suggested that the digital microscope would be a way to "put up [images] and present to the entire class." Also, the teacher thought that using the digital microscope would allow everyone to "see everybody's screen at once." The teacher anticipated that using the digital microscope would be a way to "import [images] into other [software] like Word or PowerPoint." Also, the teacher thought that using the digital microscope would help students "manage taking a digital photograph." The teacher expected that using the digital microscope would allow students to "maneuver it [and] import it into other programs." Also, the teacher thought that in using the digital microscope the students would "boot up to a computer and play," "make mini-movies," and "capture the images and hold them." The teacher suggested that digital microscopy will be a way to "take a photo with it and put it in [the student's] file."

About the digital microscope's computer technology, the teacher noted that the digital microscope will allow students to "[see] how different pieces of technology increase knowledge." Also, the teacher anticipated that using the digital microscope would permit students to "[see] how different pieces of technology increase productivity."

Researcher summary (computer) from pre-interview: In teacher remarks coded in the category *computer*, Teacher E spoke about what the teacher expected that the students would see and do using the digital microscope. With regard to the digital microscope computer aspects and teaching a lesson, Teacher E spoke about showing images to the whole class at one time and how the teacher and students should be able to see all computer monitors at one time. The teacher also spoke about making digital images and importing those images into other programs. The teacher noted that students would play, make videos, and make images that they wanted to keep in their digital files. With regard to the digital microscope's digital technology, the teacher expected that this technology would be helpful in creating knowledge and increasing productivity.

Post-interview 2004

Remarks group E-iii-P4 1 of 5. Teacher E found that in using the digital microscope, the students "save things … [and they say] 'oh, I want to keep this,' 'I want to e-mail this home,' [and] 'I want to … [do] … those kind of things.'" The researcher noted that the teacher found out students were able to utilize the computer functions of the digital microscope to store images and videos. This had the potential to allow image or video use later either in the home setting or to keep as a file as school. This showed a change in what the students could do with the data they collect, which in this instance was the photographic record of the images they observed under different magnification and lighting. This could not be done in previous lessons using the light microscope. The digital microscope gave the students the ability to re-examine the images that they at first observed and then selected and sent to be stored. The teacher found that the students wanted to keep images and e-mail them home. The researcher noted that the teacher discovered that in using the digital microscope the students have an interest in saving what they discovered and being able to send it home by email. The digital microscope and its relationship to the computer allowed the students to be able to do this.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about student-driven investigation and the students' desire to share images from school work at home. Teacher E noticed that the students themselves began to direct their inquiry using digital microscopy. Roth (1999) discussed students' phenomenological understanding of topics where there were classroom discourses about the materials at hand. Student driven inquiry as a part of this phenomenological understanding was essential to learning, according to Roth (1999). Pea (1994) addressed concepts of student communication as a part of student learning. He discussed the fellowship aspect that communication (discourse) brings to students within their community. Students' wanting to share is natural and shows their reaching out to their community for validation and to gain insight.

Remarks group E-iii-P4 2 of 5. Teacher E stated that in using the digital microscope, the students "use some of the special effects ... learned in art class." The researcher noted that the students were able to apply what they learned in art class with the digital microscope (specifically, using the special effects functions) to the digital microscope lessons in the enrichment class. The knowledge the students learned in one class helped in another totally different class using the same instrument. The computer aspect of the digital microscope helped make this possible and the science and technology aspects of this device made doing lessons in both art and enrichment classes possible. This kind of learning involves a *scaffolding of learning*. This was one of the first times that the researcher clearly observed this scaffolding of learning using the digital microscope. This effect showed the potential for collaborative teaching using the digital microscope's computer functions, which would not have been possible using only the light microscope or just the magnifying glass.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about scaffolding of learning and art-science connections. Roth (2003) discussed the impact of scaffolding of learning, which involved the use of prior knowledge in student learning. Donovan et al. (1998), Bouillion and Gomez (2001), and Lovrich (2004) noted that it was essential for teachers to tap into this prior knowledge in order to help students construct new knowledge for themselves. What we saw was a variation on this theme, in which the students brought prior knowledge from another class and applied it to a science lesson in digital microscopy. The similarities in art and natural science activities have been reviewed by Wright (2000) and other researchers. That students would make this scaffolding connection could be understood in the observations of Wright (2000), who noted that artistic imagery and scientific investigations involving graphics share the aspects of material qualities and hidden attributes. Pestrong (1994) noted that students who have little interest in science (or alternatively in art) may develop appreciation for both when working with graphical representations that hold both an artistic and scientific quality.

Remarks group E-iii-P4 3 of 5. Teacher E found that in using the digital microscope, the students were "able to move some samples out ... put the real object [underneath and make an image], print it out, [and] enlarge the object ... to see the difference." The researcher noted the students made comparisons about the real object in three dimensions, a two-dimensional view of the object, and the enlarged two-dimensional print of the object. Researchers might better understand how the teacher discovers what students are seeing in numerous ways; their discourse, the printed image, the enlarged printed image, and the use of video. The computer component of the digital microscope was important for this transfer of images from three to two dimensions and for the students to be able to compare the differences.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about three- and two-dimensional representations of objects and student learning. Jones et al. (2003) noted that student knowledge of shape and scale were significantly enhanced when students worked with objects and their computer-based representations at the same time. Roth 1996b) discussed what he called tracers, which are both artifacts and representations of objects that are used to advance learning and understanding by principle actors in a classroom community. Teacher E may have noted this sort of behavior among students as they grappled with the objects and images. The students' experiences with objects and two-dimensional enlarged images of them was the theme of a popular book *Close Closer Closest* (Rotner & Olivo, 1997), which explored students' views of perspective and scale. By presenting progressively closer views of things that young children encounter every day, Rotner and Olivo showed how the viewer's perspective and understanding can be changed. Teacher E was describing something similar in this instance.

Remarks group E-iii-P4 4 of 5. Teacher E noted that in using the digital microscope, the students would "take a movie of their [own] eye." The researcher noted that this was one of the things that Teacher E earlier noted the students would look at with the microscope. The change from before was that the students did not only look at their own eyes on the screen but were able to record the movement of their eyes using the video function of the digital microscope. This could not be done with the standard light microscope. The teacher observed that the students used the video function of the digital microscope to record something that they normally could not observe. The research noted that the computer function of the digital microscope allowed the teacher to find out what interested the students and what they did when they were interested, in this case video the movement of the eye. The change here was that the teacher learned more about what students did and in what they were interested.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about what interested the students and how they explored that interest. Roth and McGinn (1998) discussed the lack of learning environments where students can conduct investigations in an authentic way. Included in the authentic concept were student-driven inquiry and the pursuit of what interested students. Teacher E has remarked on the success of this type of inquiry in these comments.

Remarks group E-iii-P4 5 of 5. Teacher E noted that in using the digital microscope, the students "[use] the special effects," "[make] sound [with] the little movies," "make those little movies," and "step into the special effects, and the painting, and the labeling, and the making [of] a movie and those kinds of things." The researcher noted that the teacher was specific about what the students did with the digital microscope and its computer capabilities. The students used special effects, including: sound with movies; painting and labeling; and others, all which could be done with student-made images or videos from the digital microscope. The researcher thought that the change occurred in the teacher's learning about what functions the students used in special effects. This in turn informed the teacher about what the students did; this also related to the students' interest.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about what interested the students and how they explored that interest, including digital enhancement of images using graphics functions of the digital microscope software, and the open-ended nature of the enrichment lessons using the digital microscope. Learning environments where students could conduct investigations in an authentic way feature student-driven inquiry and the pursuit of what students are interested in, which might lead to very open-ended types of lessons (Carin & Sund, 1970; Liem, 1987; Friedl, 1997). This kind of learning, which involved a classroom community of students engaged in discourse and discovery, was also described by Roth and McGinn (1998) and Roth (1996b). Teacher E had remarked on the success of this type of inquiry in these comments. Teacher E also mentioned that the students liked to explore modifying images using the graphics software. This enhancement had a wide range of applications from labeling images to adding color and patterns to images (Prime Entertainment, 2002). Teacher E included exploration of these image enhancements as part of the lesson, which seemed to also help captivate student attention.

Post-interview 2006

Remarks group E-iii-P6 1 of 1. Teacher E stated that in using the digital microscope, the students "learned how to focus, how to … focus on a computer [screen], but focusing their own attention on something is something else] … and it is all about getting your attention focused on whatever." The researcher noted that the teacher mentiond focusing – *not just the digital microscope* – but focusing on the students' attention. Teacher E remarked that it was "all about getting your (students') attention *on something*". The shift here was from the students using the special effects of the digital microscope's computer capabilities to using the digital microscope as a means to get students' attention "*focused* on something or whatever" as Teacher E noted. The researcher noted that the teacher's statement showed a change in the way the teacher approached the subject of the focusing of students' attention. The teacher changes from focusing using the digital microscope as a tool to focusing the digital microscope regarding students' attention. The researcher found that this was a leap in how the teacher perceived the benefit of the digital microscope. In earlier comments, Teacher E had anticipated what the students would do when they were introduced to the digital microscope. This evolved into observing the students using the various aspects of the digital microscope and its compatibility with various programs on the computer (i.e., special effects, labeling and downloading, storing, and sharing these files). The researcher noted other changes that occurred from what was anticipated by Teacher E mentioned previously in post-computer 2004 interview analysis. In this interview, the researcher noted that Teacher E had shifted from observing what the students were *doing* with the digital microscope and its components to student *behavioral* observations and remarks on their *attention*. *Focusing using the microscope* had changed to also include the focusing of *student attention utilizing the digital microscope*.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about the focus of student attention, student change, and the effect of the digital microscope as a new tool for inquiry. Roth (1994) discussed the effect of focus of student attention during scientific discourse when a representational device is in use. Teacher E noticed this effect and remarked on how the digital microscope focused student attention. The use of special tools for inquiry was a topic of inquiry for Roth (1996b), who remarked on how the introduction of a tool could remarkably transform the setting for student learning.

Interview after first lesson 2004

Remarks group E-iii-A4 1 of 8. Teacher E found that in using the digital microscope, the students wanted “[to] save it in your [the student's] folder and then ... pull it up from your [the student's] room” and “[to] save it [their image] ... put it in your folder on the file server and ... access it from your [the student's] classroom.” The researcher noted that Teacher E mentioned using the digital microscope as well as the students’ being able to save the images that they made in the laboratory during the science lesson. The student’s electronic file folder was accessed later from the student’s homeroom. The researcher noted that these images could then be used later by the students, and shared with other students in the homeroom, other students in the enrichment class, the homeroom teacher, and at home with the student’s family. The researcher observed that there was a change in the way students dealt with images because of the ability to save the image and have it available for observation later because of the computer capabilities of the digital microscope and the networking of computers in the school. The digital microscope and the computer each became a *lens* that provided an insight into what the students wanted to save and what the students did with the saved image later. The researcher noted that Teacher E was very specific in remarking on what the students did with the saved images. These remarks also informed the researcher about what the teacher found important that could be done with the digital microscope's computer capabilities (i.e., save it in a student's folder, pull up that folder in another classroom, put it in their own folder on a file server, and then access it from another classroom). In this regard, the researcher observed a change from the pre-interview 2004. In this interview, the teacher exhibited greater detail and familiarity with the computer aspects of the digital microscope. The change facilitated by the new technology of the digital microscope also revealed what the teacher found to be of importance, not only to the students but to the teacher.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about how student learning was affected by the capability of the computer accessing student images later on in different places. Jones et al. (2003), who studied technology-mediated inquiry, spoke about haptic perception among students, which related to both touch and visual perceptions of objects. The students in this instance touched and manipulated the object, but later were engaged in understanding what the encounters with the object meant. In this regard, being able to access the images in different settings and interact with others about the images added a new dimension to the learning experience and increased the students' perceptions about the objects they imaged.

Remarks group E-iii-A4 2 of 8. Teacher E found that in using the digital microscope, "we [use] the same methods that we [enrichment class] use as far as using a program Word or PowerPoint or anything else – this is just a program." The researcher noted that Teacher E used prior knowledge about Word and PowerPoint, which became part of the scaffold that reinforced the teacher's instructions for using the digital microscope. The teacher built on the foundation that the students had from working with computers both in the homeroom and the enrichment class. The teacher compared what they were doing now with programs that the teacher already had confidence in using. The teacher had confidence using new technology by utilizing a pre-existing skill that the teacher had in computers. This confidence then was something the teacher conveyed to students by saying ‘this is just a program’ like the others that students have used before. The researcher noted this change in outlook by the teacher. In addition, Teacher E noted that in using the digital microscope, the students “[use computer] programs they are already familiar with.” The researcher noted the connection to computer programs that the students were familiar with. Teacher E showed confidence with the students’ familiarity with the new digital microscope programs built on their knowledge of computer technology. The researcher noted the change in confidence of the teacher and students using the digital microscope because of their own experience with other computer programs.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about building on prior knowledge. Donovan et al. (1998) and Lovrich (2004) discussed the critical importance of teachers drawing on pre-existing understandings of subject matter in the teaching process. Bell and Linn (2000) would have called this knowledge integration. Teacher E employed such a strategy here using personal experience and the students’ prior knowledge.

Remarks group E-iii-3 of 8. Teacher E found that in using the digital microscope, “if you have the laptop, you can just go outside with it.” The researcher noted that this was a change in the view of the teacher – going outside the classroom. Such a change in environment had the potential to open up other opportunities for lessons that were not possible previously in using the light microscope. The researcher noted that the teacher envisioned going beyond the walls of the classroom.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about taking the digital microscope outside and what a change in environment might do for student learning. Richardson (1990) noted that with all teacher change, the personal biography of a teacher was of utmost importance. Teacher E at some point probably experienced outdoor learning and was open to this change. Teacher E has experienced classroom success in digital microscopy and this success caused her to muse about other possibilities. For Roth (1997), the improvising nature of outdoor activities would be a strong contributing factor to authentic student inquiry.

Remarks group E-iii-A4 4 of 8. Teacher E mentioned that in using the digital microscope “it is taking pictures and you are seeing, but it is different [than a camera].” The researcher noted that Teacher E differentiated taking pictures with the digital microscope and the digital camera. The researcher noted that there was a change in how the students see with the pictures taken with the digital microscope. Teacher E also noted that in using the digital microscope, the students “like taking a picture of it.” The researcher noted that the teacher found that the students enjoyed the picture-taking capability of the digital microscope, which allowed the students to see in a different way than a traditional camera. In addition, Teacher E found that in using the digital microscope, the students were “making a movie, but not that kind of movie [more like a video].” The researcher noted again that Teacher E differentiated between making a video with the digital microscope and the movie camera. Teacher E related that in using the digital microscope, the students were “making that connection to see it as a microscope rather than [camera or video camera].” The researcher noted that the teacher still wanted the students to see digital microscopy as a science tool even though it had features of a camera or video camera. The teacher differentiated between using a movie or video camera and using the digital microscope to view and then capture images through time.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about different ways of seeing for students. Jones et al. (2003) discussed ways of seeing by students and concluded that microscopy gave students a view of scale and shape that was unique. Teacher E noticed this difference between digital microscopy and what might be the nearest thing to it, camera photography. Also, the use of new tools that have a profound effect upon learning environments had been studied by Roth (1996b) and Jones et al. (2000). That students would be able to make the distinction between the digital microscope tool and a similar tool (the camera), was predicted by Jones et al. (2003), who noted the special perception skills of students who use electronic microscopy in the classroom.

Remarks group E-iii-A4 5 of 8. Teacher E noted that the digital microscope “piggy-backed on the technology, definitely.” Teacher E also noted that the digital microscope had computer programs similar to the programs that the students knew already. The researcher noted that ‘piggy-backing’ showed a change that had taken place. Learning was being reinforced through prior knowledge and bridging the connection from already known computer technology and similar aspects of this technology utilized in digital microscopy.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about ‘piggy-backing’ of knowledge. As noted previously, Donovan et al. (1998) and Lovrich (2004) discussed the special importance of teachers drawing on pre-existing understandings of subject matter in the teaching process. Teacher E employed a similar strategy using the students’ prior knowledge of similar technology.

Remarks group E-iii-A4 6 of 8. Teacher E stated that in using the digital microscope, the students would “save it [their work] like you normally do.” The researcher noted that showed a routine, and the teacher was drawing on this routine and familiarity with it, to connect to similar technology of the digital microscope. The researcher noted the confidence that the teacher exhibited concerning the knowledge of the students about computer programs especially ‘saving it.’ As before, the change was in the confidence level of both the teacher and the students in using computer programs and having this cross over to using the digital microscope technology. In addition, Teacher E remarked that in using the digital microscope, students wanted “to launch a program,” one of the computer aspects of digital microscopy. The researcher noted that again the teacher was using the computer aspect of ‘launching a program’ to connect students to using the digital microscope.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about confidence in new technology, familiar routines, prior knowledge, and new learning. Teacher confidence in new technology was one of the criteria noted by Richardson (1990; 1991) as key to success in teacher change and the implementation of new programs. As noted previously, Donovan et al. (1998) and Lovrich (2004) discussed the importance of teachers drawing on pre-existing understandings of subject matter in the teaching process. Teacher E employed this strategy in using the students' prior knowledge of similar technology.

Remarks group E-iii-A4 7 of 8. Teacher E found that in using the digital microscope, the students would "add some visual effects," "add sound," "make a movie," and then "save what he [the student] was doing to his folder on the file [server]." The researcher noted that Teacher E again used the digital microscope as a tool in a lesson and then applied what the students knew to add to the lesson using the computer programs already familiar to students such as visual special effects, sound, and labeling. The student then saved this to the student's folder on the file server. This capability was not possible before the introduction of digital microscopy to the students. The change that the researcher noted was in being able to work with an image that previously only the student viewing the object could see alone. In the past, once the student left the microscope that image could not be shared with other students or teacher, manipulated, recorded, or stored for later viewing.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about the application of prior knowledge in student learning and the sharing of digital microscope imagery. As noted previously, Donovan et al. (1998) and Lovrich (2004) discussed the importance of teachers drawing on pre-existing understandings of subject matter in the teaching process. In this instance, Teacher E employed this strategy in using the students' prior knowledge of similar technology. Roth et al. (1999) discussed the importance of sharing artifacts and imagery in community learning, which they noted would provide anchors or bridges to learning. The way that digital microscopy was used in this instance was an example of this kind of learning.

Remarks group E-iii-A4 8 of 8. Teacher E found that in using the digital microscope, the students can "put it on the [monitor] for all of them to see it." The researcher noted that Teacher E was able to have all students to be a part in the viewing of an image. Also, the researcher noted the interactive nature of what the teacher and the students did in the lesson. The change was in this interactive capability provided by the large screen (and the student monitors). Previously, each student could only view things individually (with a standard microscope) and then discussed what they saw; they could not discuss a common image that all could see at the same time. The researcher noted that the teacher found that it was important for all the students to see the image at the same time.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about all students seeing digital microscope images at the same time. Roth (1994; 1999) wrote about how important it was for students to be able to share information in order to have the emergence of science-related discourses necessary for effective community learning. Roth (1994) noted the importance of all students having access to the representational device at the same time. Roth (1999) noted how important it was for students to work and interact on the same issue at the same time. Teacher E discovered that this simultaneous sharing of imagery and ideas was important in the digital microscope laboratory.

Interview after lessons 2006

Remarks group E-iii-A6 1 of 2. Teacher E found that in using the digital microscope, the students "learned that there are two different ways to install it [but] … there is [only] one way to install it that you do not have to use the disk." The researcher noted that Teacher E was being specific about a function of the digital microscope that the teacher learned was important. Installing the program by using the disk [CD] and installing the program so that you do not have to use the disk was important to this teacher.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about helpful prior knowledge. As noted previously, Donovan et al. (1998) and Lovrich (2004) discussed the importance of teachers drawing on pre-existing understandings of subject matter in the teaching process. Liem (1987) addressed the importance of allowing sufficient time for lessons and how this was important for inquiry lesson success. Teacher E allowed for sufficient time and this resulted in lesson success.

Remarks group E-iii-A6 2 of 2. Teacher E found that in using the digital microscope, the students "use it to take a picture and then we are going to label it the same way … and for them to say 'oh, when I am typing on this and I am labeling on that program' and 'I can also label my objects' on this too." The researcher noted that Teacher E observed what the students said and made the connection from what the teacher was doing to what they could do. The students were then able to 'piggy-back' off of the teacher's instruction. The teacher and the students' prior experience with other computer programs helped them make the connection to what programs they could use in this instance after they took a picture of their object, which they observed using the digital microscope in a science-enrichment lesson. The teacher showed an example to the class, and the students were able to apply what the teacher remarked about and continue on their own. In this example, the teacher was modeling a task with the use of the teacher's prior knowledge and experiences. This modeling served as a starting point for the students who were then able to connect to their own prior knowledge and add their own input and individuality to what they were going to do. The teacher, being a model, then became a participant observer and was able to find out something about the capabilities of the students and also their own uniqueness and their connection to their own project. The safe environment that the teacher provided for the students was evident in their ability to freely share what they were going to do as well as being confident to go in the direction that they wanted to go and were interested in. In this way, the teacher was able to discover what interested the students and what they were capable of doing. Also, the teacher gained a glimpse into what prior knowledge they were bringing to the task, and finally discovered a great teaching moment sharing with the students. When the students did what they wanted to do with the picture they made, this gave the teacher an opportunity to observe what the students were doing (labeling) and saying (community dialogue). The change here was the opportunity that the digital microscope provided for a safe, interactive environment based on the ability to take pictures of images observed in an enrichment science lesson.

In teacher remarks about *computer* with regard to the digital microscope, Teacher E spoke about a safe learning environment that stimulated the interest and individuality of students, students sharing in what they were going to do, and helpful prior knowledge. Liem (1987) wrote about the importance of a safe and stimulating learning environment for inquiry students as part of his treatise on inquiry-based learning. Teacher E provided that environment for the enrichment students and acted as a role model for them (Liem, 1987). As a result, the students' own ideas 'piggy-backed' on the teacher's own instructions for the lessons. As noted previously, Donovan et al. (1998) and Lovrich

(2004) discussed the importance of teachers drawing on pre-existing understandings of subject matter in the teaching process. Other instances of this effect have been discussed previously in this category.

Category – Connection

Pre-interview 2004

About the digital microscope and its connection to teaching, Teacher E anticipated that digital microscopy would be a way to “get them into anything we want to lead them into.” And, the teacher thought that digital microscopy would “[lead] definitely from sciences into writing” and in using the digital microscope, lessons will “go into the sciences and math.”

About the digital microscope and students’ reaction, the teacher suggested that students would be “exploring” and would “gain confidence that can spill over into anything.” And, the teacher felt that digital microscopy would help students “explore learning” and would “enhance a lot of different areas.”

Researcher summary (connection) from pre-interview. In teacher remarks coded in the category *connection*, Teacher E spoke about what the teacher expected that the students would see and do using the digital microscope. With regard to the digital microscope and the connection to teaching lessons, the teacher mentioned leading students into other areas of inquiry, the many possibilities of different studies, and a connection between digital microscopy, mathematics, and writing. With regard to the digital microscope and the connection to students, the teacher mentioned confidence that would be gained using the digital microscope, enhancing learning in many areas, and students’ exploring with the digital microscope.

Post-interview 2004

Remarks group E-iv-P4 1 of 7. Teacher E found that by using digital microscopy students engaged in "[lessons using] crystals" and commented on how studying the crystal's "shapes move over certainly from science to math." The researcher noted that the teacher was very specific about lessons using crystals and shapes of crystals in lessons that would be extended from science to math lesson. Earlier, the teacher anticipated extensions in math but the teacher now informed the researcher more specifically about the part of the mathematics curriculum involving shapes related to lessons on crystals using the digital microscope. The researcher noted that the teacher, through experience with the students using the digital microscope in a science lesson, was able to extend the lesson to shapes in mathematics. This showed a connection through science and technology to math and, in this instance, shapes or geometry.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about connections to mathematics, specifically shapes and geometry. Chi et al. (1994) noted that conceptual change is easy if the concepts are ontologically compatible, which seemed intuitively correct for crystal study and shape or geometry. Teacher E thought of this compatibility in suggesting that crystal studies could 'move over' into related areas.

Remarks group E-iv-P4 2 of 7. Teacher E found that in using digital microscopy the teacher's lessons "pick[ed] up some art in it and … in the original lesson that we were exploring, they would take a lot of things and just manipulate them in artistic ways." The researcher noted that Teacher E mentioned the specific connection to art. The teacher stated that beginning with the original lesson the students would "take a lot of things and manipulate them in artistic ways.” What was interesting about this comment was that the students were exploring and in that exploring would lead them to manipulate a lot of things in artistic ways. The connection to art was important here. The teacher mentioned that the students changed from the original lesson through exploration and manipulation. They were able to express themselves in an artistic way. In the pre-interview, Teacher E did not mention art but mentioned math and writing. Therefore, in the teacher’s perspective, the change here was that other areas of the curriculum such as art also could benefit by digital microscopy.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about artistic connections and manipulation of objects and student exploration. Gehlbach (1990) made a distinction between expression art and communication art. In this instance, however, it seemed more that communication art (images meant to convey ideas) also became expression art (the work of artists) from the teacher’s perspective. Wright (2000) noted the similarities of art of either kind to science, saying that the two were inextricably linked because of their mixture of depiction and meaning. Teacher E found that students manipulated objects in digital microscopy and produced images that were also works of art. The teacher discovered this connection in this part of the activity.

Remarks group E-iv-P4 3 of 7. Teacher E mentioned that by using digital microscopy students made “some connection back and forth [manipulating crystals and shapes from science to math to art].” The researcher thought that this was an important statement about connections. Also, the researcher noted that by manipulating crystals and shape in the science lesson, the students went ‘back and forth’ from science to math to art and back to science. The researcher noted that the teacher was specific in citing the example of using crystals in science activities involving the digital microscope. This back-and-forth connection reinforced the learning.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about bouncing between digital microscope observations (of crystals), the digital imagery, the art functions of the digital microscope, and art. Chan (1994) and Wright (2000) made the argument that natural science and art were inextricably linked because of the dual nature of most art, namely the practical function of the art and its deeper meanings. That students would move back and forth in this realm was not unexpected, in the view of Wright (2000). Roth (1994) presented the view that students would use all manner of representations and signs to convey their opinions during discourse on a topic being studied in a learning environment that was open to exploration and conversation. Later, Roth (2003) made the argument that students' cognitive development was aided by graphic representations and the scaffolding that making such representations provides for their learning. These literature connections suggest that at least some of the basic concepts being observed here were grounded in previous work, although the specific 'back and forth' noted here was different.

Remarks group E-iv-P4 4 of 7. Teacher E noted that in using digital microscopy students "[employ] things that they [the students] had learned in art and pulled it back in [to the science lesson in enrichment class]." In this instance, the researcher noted that this was a different aspect of art than was previously discussed. The connection here was between two areas of the curriculum taught by different teachers, who used different media and lessons. The students were able to apply what they had learned in art using the digital microscope and conveyed that learning in a new way to a science lesson in an enrichment class. This showed a student connection between different classrooms and their teachers and it impacted lessons involving different subjects and materials. The back-and-forth connection previously discussed was evident here but in a different way (between enrichment and art classrooms).

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about how students were able to take what they had learned in art class (using digital microscopy) and brought it into this teacher's science classes, which also used digital microscopy. As noted earlier, Chi et al. (1994) noted that conceptual change was easy if the concepts were ontologically compatible. In this instance, the compatibility was related to a similar tool, namely the digital microscope. Students who had previously had discourses in art class about things seen in digital microscopy continued that discourse, but in a different way here. Roth et al. (1999) spoke about the importance of artifacts (imagery, in this instance) and classroom discourse in problem solving among a community of learners. This seemed to be manifest here with students continuing the dialogue they had in art class in the science lesson. In this way, the mechanism of scaffolding between classes emerged.

Remarks group E-iv-P4 5 of 7. Teacher E found that using digital microscopy one could "look at something and do some measurement of something [and this is math]." The researcher noted that the teacher mentioned measurement and the teacher related measurements to mathematics. In addition, Teacher E remarked that using digital microscopy the teacher could "see math and science and art flowing back and forth." The researcher noted that this was an important observation and showed an important change in how the introduction of this new technology affected a lesson in science. The teacher's mention of 'flowing back and forth' seemed particularly insightful.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about measurements using digital microscopy, their connection to mathematics, and the mathematics-science and science-art connections. As noted earlier, Chi et al. (1994) noted that conceptual change was easy if the concepts were ontologically compatible. In this instance, observing was compatible with measuring, which could be done in real time or from imagery. Jones et al. (2003) studied computer-based microscopy in classrooms and concluded this kind of microscopy was very successful in conveying concepts of scale and shape. Therefore, it seemed natural that students could move from imagery to measurement in this instance. Regarding the mathematics-science-art connection, the teacher was reflecting back on previous insights on interdisciplinary connections. For Roth (2003) this kind of scaffolding of ideas was a key part of the cognitive development of students.

Remarks group E-iv-P4 6 of 7. Teacher E found that by using digital microscopy a teacher could "bring in more measurement [into the lesson on insects]." The researcher noted that the teacher was more specific in mentioning areas of math and science that could be incorporated. Teacher E noted that in using digital microscopy a teacher could "[meet] the state standards ... whether it was math or science or art or a lot of different areas – [they could] benefit" and "be able to use it [the digital microscope] in different areas." The researcher noted for Teacher E that digital microscopy had another purpose here. By incorporating a number of different subject areas, the teachers could also meet state standards in other areas as well.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about incorporating state standards and the potential for interdisciplinary lessons. In this instance, the teacher reflected on the many connections of digital microscopy. As noted earlier, Chi et al. (1994) noted that conceptual change was easy if the concepts are ontologically compatible. These interdisciplinary connections pertain to state standards as well. As noted previously, Brand and Kalamuk (1999) discussed how the digital microscope specifically met numerous national standards, including microscopy standards such as constancy, change, and measurement (National Research Council, 1996).

Remarks group E-iv-P4 7 of 7. Teacher E related that using digital microscopy was a way for teachers to "use [microscopy] when we are studying fruit flies and we are counting this, or studying money, and we could use this when [we want to study] something [where] you don't see the individual pieces … as you magnify it, [for example] you can count how many scales are on this [animal] or how many sides or shapes [are on this object] or … this sort of thing." The researcher noted that the teacher was specific in the kinds of lessons where the digital microscope could be used. Also, the researcher noted that the teacher revealed what was important in the lesson. This importance was revealed in comments about using the digital microscope to study fruit flies, counting things, studying money, and 'when you have something that you don't see the individual pieces.' The researcher noted that more than just what was being observed was being mentioned. This teacher's comments showed a progression. When you have something that can't be seen such as individual pieces, these can be magnified, and then you can count how many scales, sides, and shapes. The researcher noted that this progression was significant and showed a change in how the teacher described the lesson. This revealed what the teacher experienced in the lesson and perhaps learned as well. Studying fruit flies became a lesson in enlargement, where the number of scales, sides, and shapes could be counted. As the teacher became more observant, the lesson became more personal and through the experience became a lesson of discovery. The key was that the digital microscope provided the vehicle to examine something and then from the investigation, which may have included counting scales or sides or shapes, increased the observational skills of the observer. This then transferred to being able to describe it in more detail. The change also included becoming more observant and gaining the skills necessary to achieve it.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about observation and discovery driving the investigation and the changing intensity of focus during lessons. The teacher made important observations in this lesson. This was a leap in the teacher's cognition of what to observe and how to integrate this in the lesson as well as transfer this to observation of student learning. Teacher change, according to Richardson (1990; 1991) was driven by the teacher's background and willingness to change. Teacher E was open to these changes because of the teacher's prior experiences in teaching and learning. The students' experiences and objects seen (insects and coins as noted in these comments) are reminiscent of the scenarios in the popular book *Close Closer Closest* (Rotner & Olivo, 1997), which explored students' views of perspective and scale, and in the web-based resources of Parker (1995) and Davidson (1995–2004).

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Remarks group E-iv-P6 1 of 18. Teacher E found that using the digital microscope was a way to keep "learning – and what we are doing can bring us full circle back around, you know, we can get more out of it than just seeing something up close." The researcher noted that the teacher discovered the digital microscope accomplished more than expected. The teacher learned that using the digital microscope accomplished more than just seeing something up close, which was different from what the teacher anticipated in the pre-interview 2004.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about 'seeing' as being more than just simply observing objects and about the significance of holistic learning. Teacher E noted that the students learned more than just how to look under a microscope. The teacher was describing how the students learned to be investigators. Roth (1996b) described this progression when discussing the change from newcomer to old-timer among the actors in a learning community. In addition, in remarking on the students 'going full circle and back around,' the teacher was describing a type of holistic learning that is based in the Piagetian concept of operational thinking, or thinking that was logical and followed rules (Bosak, 1991). This was higher level thinking and this might be emerging in this instance, as described by Teacher E.

Remarks group E-iv-P6 2 of 18. Teacher E found that using the digital microscope involved the "use of language – when they were doing the labeling – and we would talk about spelling correctly … and when you are typing in your labels – how the label can either add to [the image] or not … visual things … where is the best place to put [the image label] … [and] do you want to put your name on it?" The researcher noted that language was not mentioned in earlier comments. What the teacher described was very detailed about how language was used and its connection to visual things. The researcher noted that the teacher observed how the digital microscope opened up choices for the students and involved individual selection (‘does it need a label,’ ‘should it be added or not,’ ‘is it spelled correctly,’ ‘where is the best place to put it,’ or ‘should a name be placed on it or not’). The researcher noted that there was a strong correlation here to language and the various functions where the digital microscope supported the students’ individuality. The visual aspect of this statement not only was mentioned by the teacher but, also, the teacher was aware that not all students wanted the same thing visually. Also, using the digital microscope allowed other ways for the teacher to see what the students were doing or saying, which informed the teacher not only from the aspect of viewing the image under the objective but also by working with the image afterward and adding the components of language (as mentioned above). There were other connections to language that became evident as the students used the various functions of the digital microscope and these were not anticipated by the teacher.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about learning in other areas beyond the digital microscopy lessons, for example, in language, and students’ developing higher level thinking skills. As noted above, Teacher E remarked that the students learned more than just how to look under a microscope. Roth (1996b) noted how students made connections in the process of knowledge diffusion, especially in the area of communications or what he called tracers. Teacher E described this type of activity among student actors in the teacher’s classroom. As Bosak (1991) and Phillips (1994) pointed out, the Piagetian concept of children’s cognitive development includes several stages. In passing through the stages associated with the enrichment class' age group, students who were becoming more operational were acquiring the higher level thinking skills such as systematic reasoning. This was evident as the students worked through organizational tasks noted by Teacher E.

Remarks group E-iv-P6 3 of 18. Teacher E found that in using the digital microscope "there was math." Teacher E also stated that "I knew that I was going to use [digital microscopy] with the science area … I knew that [it] was certainly functional … but how many other curriculum areas that it would also fit into or could help" the teacher did not know. The researcher noted Teacher E acknowledged that the digital microscope would be used in science and looked to see how other areas of the curriculum might fit in. In this way, the teacher would "be able to get more objectives … together" and "be able to use more standards … together." Teacher E also noted that the digital microscope helped to "compact a few things together." The teacher was able to include multiple curriculum areas that began with a lesson in science and by compacting a few things or curriculum areas together, and could use these combined lessons to include more state standards.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about making interdisciplinary connections and satisfying state standards using digital microscopy. Making interdisciplinary connections was a change for Teacher E. Richardson (1990; 1991) observed that teachers change in accord with their own past learning and teaching experiences and comfort levels.

Remarks group E-iv-P6 4 of 18. Teacher E wanted to "be able to use what we are doing and then tag it back to maybe something [else], which will support … something

[more] that they have done in the classroom." The researcher noted that the teacher remarked on using digital microscopy in the enrichment science class, which would support learning in the regular classroom as well. The teacher was connecting the enrichment digital microscope lesson to supporting the students' learning activities in other classes. This connection was not anticipated by the teacher and the teacher's remarks reflected a change in teaching methodology.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about how enrichment activities would connect to other classes that the students took. Roth (2003) wrote about scaffolding in the process of student cognitive development, and Bouillion and Gomez (2001) noted how important it was to connect this kind of learning to real-world experiences. Teacher E noted how this type of scaffolding might have been at work here.

Remarks group E-iv-P6 5 of 18. Teacher E found that "for students to make those real-life connections – [it] matters." The researcher noted that the teacher was aware of 'real-life connections' (meaning a connection to something outside the classroom) and that those things matter. The teacher noted a broader connection to digital microscopy was possible because "maybe some [program that] …somebody saw something on the Learning Channel or the History Channel and [the student realizes] … 'oh, is this what they meant by that!'" The researcher noted that by introducing the students to certain lessons they might have made a 'real-life connection' when they saw something on a television channel and reflected back and then made the connection of 'oh, is this what they meant by that.' In this way, digital microscopy went beyond the walls of the enrichment classroom and the regular classroom and into an entirely different setting and provided a bridge for understanding. The teacher believed these real-life connections mattered to the students and was a connection to understanding. Because the students had the digital microscope experience beforehand, they could understand better in a completely different learning environment. The researcher noted this was an important statement by the teacher about how learning or understanding occurred. The digital microscope became a vehicle for the teacher that gave insight into how students gained an understanding especially from real-life connections to an experience that they had using the digital microscope.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about 'real-life connections' and their impact on students' learning and students making connections later (thinking 'oh, that is what that means'). Metacognition, the process of thinking back and making connections had been discussed by several authors, including Herrenkohl and Guerra (1998), Donovan et al. (1998), White and Frederikson (1999), Pearce (1999), and Costa (2001). These authors discussed metacognition in connection with constructivism as linking new observations to past experiences. More recently, Roth (2003) emphasized how important linked experience was in development of cognitive connections in inquiry-based lessons. Students having time to think about what new things they were processing mentally allowed the connections to occur to them. Teacher E discovered that these metacognitive connections were important to the enrichment students during work with digital microscopy lessons.

Remarks group E-iv-P6 6 of 18. Teacher E found that using digital microscopy led into other areas such as history, which the teacher could not imagine going to prior to the introduction of the digital microscope. The teacher stated that the lessons helped to “pull in history … I could not imagine … when we were doing so much with money [studying currency] … the kids were saying, when they were looking, ‘oh, there are thirteen of these,’ ‘whoa, look at this,’ [and] ‘if you look real close there are thirteen of those.’” The teacher added “and then it is like … and they kept finding like on the one-dollar bill all these *thirteens* … thirteen stripes, thirteen stars, thirteen berries, thirteen leaves, thirteen arrows, thirteen steps in the pyramid, thirteen letters this phrase, … and I [noted] ‘do you think this is by accident?’” The researcher noted that the teacher was able to connect to a lesson in history, and noted how the students were surprised in what they were seeing. There was surprise by the teacher, as well, regarding the reactions the students had as they had discourse with each other. Students were able to share their discoveries immediately regarding what they were seeing. This was possible because the digital microscope could project the image for others to see together. The teacher put the image on the large classroom monitor, and the discussion continued. In this lesson, the students started to see a pattern of ‘thirteens’ and they made exuberant remarks like those quoted by the teacher (above). The researcher noted that the teacher was able to observe what the students did or said about what they were seeing as they looked at a one-dollar bill. The teacher was able to include U.S. history in a science lesson that was originally intended to take a simple look at how a one-dollar bill appeared under magnification. The teacher remarked “do you think this is by accident?” as the teacher encouraged students to examine why there are thirteen of some many different items. The students explored, discovered on their own, and ‘piggy-backed’ on what others were finding and sharing. The researcher noted the importance of discourse, serendipitous discovery, and student exploration (seeing for themselves) of what they found, as well as well as looking at what others were finding. The researcher also noted the teacher's excitement and noticed the detailed description the teacher gave of what happened when the students began to discover something that genuinely surprised and intrigued them. Also, the researcher noted that the teacher commented "well, I have never!" in amazement of how the lesson developed. The researcher noted that this was a very important observation by the teacher, which informed the researcher of how students learn from the perspective of the teacher when the teacher observed – as well as participated in – the lesson and discovers things that would not have been able to be anticipated as the teacher began. The teacher had begun by saying 'pull in history? … I could not imagine where!!'

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about student learning and excitement while studying currency, which was conveyed from the perspective of the teacher. Liem (1987) wrote about excitement conveyed from teacher to students and vice versa and how important that was in collaborative inquiry lessons. Educational researchers (for example, Gaskell, 1992; Bencze & Hodson, 1999) have viewed authentic science, such as the digital microscopy described here, as collaboration. The collaboration reported here was mainly between teacher and student, not involving an outside participant. Rahm et al. (2003) noted the main characteristic of authentic science resulting from collaboration was the emergent property of the work. Here, the discovery of history in connection with the science of microscopy was entirely emergent (not anticipated by the teacher).

Remarks group E-iv-P6 7 of 18. Teacher E found that in using digital microscopy a teacher could address curriculum standards, but that "a lot of it was accidental." The teacher added that "the more you use something," the more ideas a teacher has "and, I am real excited to get some new ideas for next year." The researcher noted that, as in the discussion of the lesson on examining the one-dollar bill, the teacher was able to address curriculum standards mostly by accident. In addition, the researcher observed that the more that the teacher used the digital microscope, the more that the teacher could make connections to other curriculum standards. The researcher noted that the teacher was excited about getting some new ideas for next year's curriculum. The excitement that the teacher experienced in the lesson with the one-dollar bill crossed over on a professional level to the teacher's being able to address curriculum standards in other areas besides science. In this instance, history and social studies were brought into the lesson. The researcher noted that the more that a teacher used digital microscopy, the more that the teacher might be able to connect learning to other areas of the curriculum. It was necessary for the teacher to use digital microscopy in order to connect to more areas of the curriculum. These connections could not have been anticipated as they were a product of the teacher's interaction using the digital microscope in a lesson and the more the teacher used the digital microscope the more ideas the teacher had.

In addition, Teacher E discovered that in using the digital microscope, a teacher could "do science, definitely." The teacher did not elaborate here, but the connection of the digital microscope and science were clearly fixed in this teacher's mind. Teacher E also found that in using the digital microscope to study currency, a teacher could "[look up] features that [the U.S. Treasury Department] is putting in place to [make money] not easy to duplicate … because our technology is moving so quickly people are pretty … good at counterfeiting … there are certain things that they do [to stop it], and it is such a secret that nobody knows how to do it … and [yet] there is somebody out there … trying to figure all that out … and they have their own little machines.” The researcher noted this connection with counterfeit prevention. It was an interesting point and came out of the discussion with students about the intricacies of the currency they were observing. This evolved from the introduction of the digital microscope to the study of currency, and the researcher noted the detail that the teacher revealed about the lesson and the findings that were uncovered.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about curriculum change, unanticipated connections, and the excitement of the digital microscope lesson on currency. Richardson (1990; 1991) wrote about teacher’s willingness to adapt to curriculum change in terms of teacher background. Teacher E had shown a willingness to change in previous comments, and this is was likely related to the teacher’s background. As noted above, Rahm et al. (2003) stated the main characteristic of authentic science resulting from collaboration was the emergent property of the work. Here, the discovery of interdisciplinary applications in connection with the science of microscopy was entirely emergent (what the teacher calls accidental). Teacher E speculated on what might emerge next and how excited the students were about what they might find. Liem (1987) wrote about excitement and how important it was in the inquiry classroom, and Parker (1995) wrote about the special fascination that young students had with the details of currency. Teacher E was excited and conveyed this to the students, and they in turn conveyed excitement to the teacher.

Remarks group E-iv-P6 8 of 18. Teacher E found that a teacher could use the digital microscope to “look at the serial numbers (on U.S. currency) … and looking at … (the) endless things that they will bring up.” Teacher E noted that students asked “why is this like this?" to which the teacher replied "I do not know; we have to look it up [because] I do not know." The researcher noted that the teacher mentioned what the students did when they were looking at small details like the serial numbers on currency. There was a give and take consisting of 'why is this like this?' from the students and 'I do not know … we have to look it up' from the teacher. The researcher noted that the students brought up 'endless things' that they found by looking at things like the serial numbers on currency. The change here was that using digital microscopy encouraged student research, inquiry, and their having to look up things they did not know.

In addition, Teacher E discovered that in using digital microscope, the students "started learning about currency," for example; they were "talking about the bills and how quickly they wear out." Teacher E added "that was another thing … we learned through using some of the web-sites of the US mint – this dollar will last this long, a five-dollar this long, a ten-dollar this (long) … and, you know, fifty-dollar bills last longer … hundred-dollar bills last a lot longer … and I [asked] 'well, why is that?'" The teacher went on to say "a one-dollar bill ... it does not last long, only so many months … and that is typical use, of course … but [for other bills, they last] eighteen months for this one, fifteen months for this one, twenty-one months for that one … and, but then, they said, 'yeah, but if you have a hundred-dollar bill' [and] I said 'exactly, they are not used as frequently,' but the one-dollar bill and the five and the ten a lot more, and the twenty a lot more." The researcher noted that the teacher began the lesson with a focus on currency and then it turned to digital microscopy. Because the digital microscope's computer was connected to on-line resources, the students could use the web-sites of the U.S. Mint and could read about how long bills of various denominations last in normal circulation. The researcher noted that using the digital microscope had the capability of encouraging students to go on-line to research a topic they were studying up close. The change that was noted here was that digital microscopy could help promote research at the moment the students are interested – at the time they wanted answers to something they discovered using the microscope.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about inquiry driven by the students and student interest in the research aspect of the lesson. As noted above, Rahm et al. (2003) found the main characteristic of authentic science resulting from collaboration was the emergent property of the work. In this currency exercise, Teacher E found that students could drive the lesson and make their own inquiries ('why is this like this') and then could do research on their own, using Internet resources. The on-line resources, which could easily be shared by all in the room at the same time, became part of the lesson, further allowing social construction of knowledge (as described by Roth and McGinn, 1998, and Jones et al., 2003, among others).

Remarks group E-iv-P6 9 of 18. Teacher E discovered that when making a connection with mathematics the students "were surprised, you know, it was like 'oh, wow, that is a real thing,' not just a made up something for math." The researcher noted that the students informed the teacher of how they were surprised by something they saw and thought about. Students said 'oh wow' and 'that is a real thing' in expressing their feelings. The teacher believed that the students wanted things to look at that were real. The change here was that by using the digital microscope the teacher was able to find out what kind of math was important to the students according to what they spoke about.

Even though the teacher originally anticipated that the digital microscope would have a connection to mathematics, the mathematics connection surprised the students.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about student feelings regarding what they were studying and the connection to mathematics. As pointed out by Shepardson (2002), Hawley (2002), and Ford (2003), young students would tend to think of natural materials in relation to how they feel about those materials relative to themselves. Rooted in this may be the desire to study something 'real and not made up.' Teacher E observed that the students had this desire with regard to this lesson and its materials. That the connection to mathematics surprised the students, was not unexpected. According to Tytler and Peterson (2004), young children commonly separate evidence from theoretical considerations like mathematics.

Remarks group E-iv-P6 10 of 18. Teacher E found that the digital microscope would help teachers include "technology, with our new technology curriculum out there." The researcher noted that the teacher did not mention technology in the pre-interview but this seemed to be an issue on the mind of the teacher now. In a related comment, Teacher E noted that digital microscope would fit in "easily with math, because I think … with doing the shapes and doing the figures and the crystals" digital microscopy was a good match. In this interview, the teacher became more specific about the ways that mathematics could be used with digital microscopy and in relating mathematics to science. The change here was that the teacher became more specific in the connection of the digital microscopy to other areas of the curriculum.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about curriculum connections, especially technology and mathematics. As Richardson (1990; 1991) pointed out, curricular change might be driven from outside as well as from the teacher individually. Teacher E mentioned the 'new curriculum out there' in reference to this external driving force for change. Teacher E might have recognized that the new technology (digital microscopy) had potential in these areas as a result of the teacher's recent experiences.

Remarks group E-iv-P6 11 of 18. Teacher E found that digital microscopy "[is] not all about just the microscopes … it is all about everything that feeds into it … I have not had any time [in class] that interest did not just bloom with them … and, [in] everything that I tried with them, I felt success … I did not have anything that just completely just flopped." The researcher noted that the teacher was pleased with the wide success of digital microscope. The teacher believed that digital microscopy involved other things that 'feed into it.' The change noted here was that the teacher developed a new outlook about how the digital microscope impacted the curriculum. From this response, the researcher learned about the teacher's success especially when the teacher stated that "I have not had any time that interest did not just bloom with them."

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about student interest 'blooming' with digital microscopy and the teacher's feeling of success with digital microscopy. As Roth and McGinn (1998) pointed out, students actively learning about nature were stimulated by visual representations of the objects studied. Roth (1999) reinforced this notion by describing how students working and interacting together could engage in science discourses, which could lead to science learning. Teacher E found that the students in the digital microscopy lessons exhibited this response. In turn, this positive feedback to the teacher was an impetus for teacher change. Richardson (1990; 1991) noted that teacher change commonly comes from the teacher when the teacher's experiences and background support what is happening in the classroom. Finally, Barab and Hay (2001) pointed out that students enjoyed a sense of ownership of findings based on inquiry lessons and that relates to the students 'blooming' as they made discoveries.

Remarks group E-iv-P6 12 of 18. Teacher E found that the digital microscope "fit into what I am already doing … but at this point, I feel comfortable enough to say at any point that if a kid walked in the door and we're doing something, I could easily even set up a center to the side, and say, 'okay, I want you to take what you have got [and] do that,' and [the other students] are going to get back to what we are doing.'" The researcher noted the comment that digital microscope could be used at a 'center' for students to use even when the teacher was teaching a lesson on something else. And, the researcher noted that the teacher 'felt comfortable enough' with the digital microscope to have a separate student study 'center' in the room. The change noted here was that the digital microscope had become a part of the teacher's classroom that could fit right in and could be used easily.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about how easily the digital microscope set up could fit into the classroom. Teacher E was expressing a comfort level with the changes brought on by digital microscopy, which Richardson (1990; 1991) would attribute to the teacher's background and receptivity to such change.

Remarks group E-iv-P6 13 of 18. Teacher E related digital microscopy to science in explaining to the students "how it may take years and years and years, to come up with one medicine for some disease, or whatever … and for them to know in the scientific world it is not all quick and fast." Teacher E then added "this machine, for us, it speeds up [the scientific process] and makes it a lot easier, a lot faster, for us to view an ant, or a leaf, or a coin, or whatever we are looking at." The researcher noted that the teacher was relating to the nature of science and made a connection to that topic by using the digital microscope with the students. The teacher revealed that the students had an experience similar to the one that a scientist might have in looking through a microscope. The teacher informed the researcher of a belief about science and a comparison of the digital microscope and technology and how it could speed things up and could make it easier to view objects. The change here was that the digital microscope helped the teacher relate to the nature of science and made a connection by using it with students.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about the nature of the scientific process and the students experiencing science. Bell et al. (2003) noted that teachers could be affected in their view of the nature of science by their experiences in the science classroom. Richardson (1990; 1991) explained that this effect depends upon the receptivity of the teacher based on the teacher's background. Teacher E conveyed a view of science to the students, who were forming their views. Kusnick (2002) noted that students come to the classroom with pre-existing views based on their experiences too. In this instance, teacher and students were examining the nature of the scientific process with regard to their digital microscope experiences. The researcher noted that these teacher remarks may reveal an important point about the implementation of digital microscopy and how it helped cause change (for example, the teacher related to the students' experience with the nature of science).

Remarks group E-iv-P6 14 of 18. Teacher E found that the digital microscope could be used for "just teaching science in general." Teacher E noted that in using the digital microscope, a teacher could "come up with more activities and … come up with more ideas on how to use them, how to implement them." The teacher added "because if you have a bank of stuff, somebody else can walk in and I say, 'I have got all these rocks' and we know what they are … they are labeled now … we have got all these different leaves or different bugs or different, you know, .. coming up with a kind package … and not to have so much stuff – we do not have unlimited storage space – but the small things you feel okay about … small sand samples, or small crystal samples, or you know, any of that kind of stuff is very useful and I suggest we look into it." The teacher informed the researcher of what might make 'something good' to use in a lesson. The teacher did not have much storage space, so space needed to be considered in lesson planning. Small things were viewed as better. There was cooperation between teachers as they shared things for digital microscopy. The change noted here was that the teacher, by using the digital microscope, came up with new lessons that kept the curriculum continually evolving.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about the practicality of small samples and how that related to the function of the digital microscope. As noted earlier, Richardson (1990; 1991) remarked on the practical aspects of teacher change and that teachers considered practicality in their receptivity to change in the classroom. In this instance, Teacher E was relating a practical aspect of digital microscopy.

Remarks group E-iv-P6 15 of 18. Teacher E stated that in using digital microscopy a teacher would “have to make [things change], like when you are making the crystals, that is the kind of a process that you want them to see it happen.” The teacher informed the researcher that the teacher wanted to observe the kind of processes that showed change in real time, such as making crystals. The change noted here was that the teacher changed from mentioning just static objects to look at, to having students become aware of change over time that was made possible by using the digital microscope video functions. This allowed the students to see a process such as crystal formation from a liquid happening over time.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about seeing change over time with digital microscopy. Chi et al. (1994) wrote about young student conceptions and their somewhat simplistic views of nature and matter. Jones et al. (2003) noted the significant advancement of student understanding and proper conceptions about the natural world after viewing small structures. In the crystal growth exercise using digital microscopy, Teacher E saw the opportunity to show students small scale change that resulted in a larger crystal forming.

Remarks group E-iv-P6 16 of 18. Teacher E discussed that in using digital microscopy the teacher “talked about copyright … it is like when you make your image – it is yours; you have created it … and then if you label it at the bottom, then you call it [yours], you have named it, claimed it as is yours … if someone else uses it, they have to get your permission.” The teacher went on to say that this “allowed us to talk about several different [ways that an image is someone's own work]." The researcher noted that the teacher was talking about ethics and this was another connection that opened up when using the digital microscope. The researcher noted that, in effect, the teacher discussed the intellectual property that the students were creating when they made and labeled an image. This discussion led into copyright issues and also to the process of creating an individual's work product. The researcher noted that this had the potential to help with the students' understanding of the ethical questions of copyright. The change here was expansion into law and ethics by having the students participate by selecting and labeling their own work.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about making unanticipated connections (for example, to ethical issues) in the lessons. As noted earlier, Rahm et al. (2003) noted the main characteristic of authentic science resulting from collaboration was the emergent property of the work. Emergent properties might not follow predicted lines, so Teacher E's class getting into ethics and copyright issues was just such an unanticipated effect.

Remarks group E-iv-P6 17 of 18. Teacher E stated that in using the digital microscope a teacher could "work on getting [additional information], through the Internet; [because there are] more sites that back up what we are doing … you do not want to send the microscopes home with the kids, but you could very easily give them a list of web-sites that have [relevant information]." The teacher added that "I am still working on my web-site." The researcher noted that digital microscopy had another connection through the Internet (relevant web-sites) that could connect to the lessons. Also, the teacher found a way to let the students continue the lesson at home, a home connection**,** by finding web-sites that supported the lesson. The researcher noted that this was not anticipated by the teacher in the pre-interview. The change here was that the digital microscope connected to the Internet, allowing research by the students. The Internet was a valuable resource for the teacher also. The teacher's development of a school web-site also would be beneficial to students.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about unanticipated Internet connections to digital microscope learning. In authentic science, emergent properties might not follow predicted lines (Rahm et al., 2003), so Teacher E's class getting into Internet connections was just such an unanticipated effect. Jones et al. (2003) found that Internet connections to digital microscopy were particularly effective if the students could not be present at the location of the microscope. They were especially supportive of an Internet connection being a vehicle for conducting and sharing science.

Remarks group E-iv-P6 18 of 18. Teacher E noted that in using the digital microscope a teacher can "learn more ways [to make connections] … just like pulling the curriculum down and going through it and finding, 'oh, this really would work – I could do this.'" The teacher added that "I just need – myself – more time, if I could figure that out." The researcher noted that the teacher mentioned the issue of time and learning ways to use the digital microscope by going over the current curriculum and deciding in what ways that digital microscopy could fit in. The researcher noted that the teacher was interested in learning more ways to integrate the digital microscope into the existing curriculum. The change here was that the digital microscope allowed the teacher to reflect on how the curriculum could benefit from using the digital microscope and connected to the time issue as well.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about future use of digital microscopy. Richardson (1990; 1991) noted that the effectiveness of teacher change was highly dependent upon the teacher embracing the change in view of the teacher's background and previous experiences. Teacher E was receptive to long-term change involving using digital microscopy and made comments to this effect.

Interview after first lesson 2004

Remarks group E-iv-A4 1 of 1. Teacher E found that using digital microscopy was a way "to work it into art lessons." The researcher noted that the teacher did not mention art in earlier comments.

In the teacher's remark about *connection* with regard to the digital microscope, Teacher E spoke about connections to art classes. There were similarities between art and natural science from the point of view of practice. In particular, both fields might generate graphics with meanings that must be interpreted (Wright, 2000). Teacher E appeared to be intuitively aware of this in making the comment about art class, which Teacher E did not teach.

Interview after lessons 2006

Remarks group E-iv-A6 1 of 2. Teacher E found that in using digital microscope a teacher could "find web-sites that have interactive [aspects] that do the same thing [we are doing] … similar, but not as good a quality, or they cannot quite see all that they can see using their own hands and their own samples." The researcher noted that the teacher was making a connection to interactive Internet sites that related to what they were studying. The researcher noted that the teacher wanted the students to compare these sites to their own investigation.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about unanticipated Internet connections to digital microscope learning. As noted earlier, in authentic science, emergent properties might not follow predicted lines (Rahm et al., 2003), so Teacher E's class potentially working with Internet connection was such an unanticipated effect. Richardson (1990; 1991) pointed out that a teacher's change is commonly related to their background, which in this instance was a computer-oriented background, which helped Teacher E embrace this approach to future inquiry.

Remarks group E-iv-A6 2 of 2. Teacher E noted that in using the digital microscope students could "go home and they can say 'this is what we did and here is a web-site that does what we did; and I can show you' … it was pretty fun.'" The teacher added that "the kids enjoyed feeling like they … 'oh, they like money,' it does not matter how you look at it … but, you know, that is [always] high interest [to them]." The teacher found that students will "say 'oh, this was in math,' or 'we did this in math,' or 'this was in science' … or 'we talked about this [one time].'" The researcher noted that the teacher revealed what the students found that was fun and that students related the experience and shared it at home. Students had high interest when they talked about what they did in the classroom and would have even more interest if they found a web-site that has similar lessons and shared at home. The words the teacher used were expressing the way that the teacher thought the students were speaking about subjects they studied using digital microscopy. For example, the teacher quoted them as saying ‘it was pretty fun’ and ‘we did this in science.’ The researcher noted that the teacher revealed to the researcher what students did or said about using digital microscopy. The change here was that digital microscopy inquiry encouraged the students to access web-sites not only in school but also at home.

In teacher remarks about *connection* with regard to the digital microscope, Teacher E spoke about student discourse in the classroom and at home. Roth (1994; 1999) and Roth and McGinn (1998) discussed the importance of student discourse in the inquiry classroom. Student discourse, including utterances and related gestures and body language, were found to be of great importance in the classroom learning community. Roth (2001a; 2003) wrote about student discourse and how it evolved over time into what Roth called scientific talk. Roth et al. (1999) noted that student discourse was part of the social configuration of learning in classrooms where students may have different levels of understanding and different backgrounds. While not part of the Roth studies cited above, it seemed reasonable that student discourse would continue into a non-school setting like the students’ homes, where parents and/or siblings might form part of an extended actor network (Roth, 1996b) for the students’ learning and understanding of new information provided by digital microscope experiences. Teacher E uncovered this non-school connection to learning and brought it out in this interview. Teacher E also noted the special fascination that young students have with the fine details printed on U.S. currency, which was discussed by Parker (1995).

Category – Knowing

Pre-interview 2004

About the digital microscope and its relationship to *knowing*, Teacher E anticipated that digital microscopy would allow students to "become familiar with how to change the lens," "become familiar with how to focus," and learn to "change to a different magnification." Also, Teacher E suggested that the students would "become familiar with how to handle [the digital microscope] on their own," and noted that the students would come to "understand the parts of the microscope."

Researcher summary (knowing) from pre-interview: In teacher remarks coded in the category *knowing*, Teacher E predicted what the students would see and do using the digital microscope. This included becoming familiar with changing magnifications and focusing, handling the microscope, and understanding its parts.

Post-interview 2004

Remarks group E-v-P4 1 of 4. Teacher E found that after the students used the digital microscope they "understand scientists a little differently." The researcher noted that the emphasis had shifted from the students understanding the parts of the microscope to the students understanding scientists differently. The teacher viewed the digital microscope, in addition to being a tool that the students use to see things that are very small, as a bridge to a broader understanding of the nature of science and the role of the scientists.

In teacher remarks about *knowing* with regard to the digital microscope, Teacher E spoke about students' understanding of scientists and being scientific. Carlson (2001) found that students' preconceptions of scientists included the view that scientists were associated with symbols of knowledge. In this instance, the symbol of knowledge could be the digital microscope. Carlson (2001) also revealed through student sketches of what students thought a scientist looked like: scientists were doing something or participating in an activity. In this instance, the activity was an inquiry using a symbol of knowledge, the digital microscope. Considering these things, it seemed likely that students would have viewed themselves as scientists, which was what Teacher E expressed in this interview.

Remarks group E-v-P4 2 of 4. Teacher E found that after using the digital microscope the students “understand the parts of a microscope better because before I don’t think they understood ‘what did what’ and at this point they will tell you – ‘*this one rocks*.’” The teacher added that the digital microscope “makes [the object] be closer and closer … and it makes the object look bigger and bigger and this is the part that focuses it and lifts the platform up and down even the simple aspects like that.” The researcher noted that the teacher was informed by what the students said about the parts of the microscope. The researcher noted that the teacher stated ‘even simple aspects like that’ to explain how the students changed from not knowing ‘what did what’ to being able to describe what each part does. The researcher noted, although these were simple aspects, they led to a greater understanding of how the digital microscope works. The researcher also found that the teacher described in more detail about how the various parts of the digital microscope work and noted the emergence of scientific language.

In addition, Teacher E stated that after using the digital microscope the students were “seeing that there are a lot of different ways to use a microscope.” The researcher noted that by using the digital microscope the students were able to extend their understanding of how the digital microscope could be used in other ways.

In teacher remarks about *knowing* with regard to the digital microscope, Teacher E spoke about how the students' had a better understanding of the function of the digital microscope and a better understanding of what they were viewing. Nakhleh and Samarapungavan (1999) studied the beliefs of young children about matter and found that a significant number did not think that there were smaller aspects about physical objects than could be seen with the unaided eye. For this reason, some children had difficulty understanding the concept of magnification and scale. Jones et al. (2003) addressed a similar issue with young children who viewed magnified objects and saw beyond everyday perceptions. As students in their study worked closely with magnified objects, the students' perceptions changed greatly with regard to knowing about shape and scale. Teacher E might have uncovered a similar effect among students in the enrichment class, who came in with their own perceptions of objects and scale. Many educational researchers, including Donovan et al. (1998) who wrote a U.S. Department of Education-sponsored volume (*How People Learn*), had expressed the view that hands-on learning environments where students can take control of their own learning and conduct inquiry were the best for both science and other classrooms.

Remarks group E-v-P4 3 of 4. Teacher E found that after using the digital microscope the students "know that things [digital microscopes] like we are using really do exist out there in real life for a job situation." The researcher noted that the teacher made a connection to using the microscope in a 'real life job' and that students know that microscopy had a place in certain jobs. The change here was that after the students used the digital microscope they knew that they were using a microscope that could also be used in a ‘real life job situation.’

In a teacher remark about *knowing* with regard to the digital microscope, Teacher E spoke about students knowing that microscopy was used in some ‘real-life jobs.’ As noted above, Carlson (2001) found that students’ preconceptions of scientists included the view that scientists were associated with symbols of knowledge. The students’ use of the digital microscope (as a symbol of knowledge) allowed the teacher to remind students that microscopes were used in scientific workplaces as well.

Remarks group E-v-P4 4 of 4. Teacher E stated that after using the digital microscope the students “know and understand that [they] were looking at the same object.” The researcher noted that this was a very important observation by the teacher. The teacher found that after using the digital microscope, the students knew and understood that they were looking at the same object under magnification; that it was the same object, but was magnified. The teacher was informed by the students that they understood that the object under the microscope was the same as the one that was on the monitor but in a closer view. This was an important concept that the teacher revealed to the researcher. The change here showed that prior to using the digital microscope the students did not know that the object and the image of the object were the same. In other words, the students came to understand that the object did not change when looking through the lens of the digital microscope. What was different was that the student could see the object closer and in more detail. In addition, Teacher E discovered that after using the digital microscope the students “understand insects a whole lot differently.” The change here was that students knew and understood insects in an entirely different way because they were able to relate what they saw magnified on the monitor to the insect under the digital microscope.

In teacher remarks about *knowing* with regard to the digital microscope, Teacher E spoke about some students thinking that the object and the image of the object magnified were two entirely different things. As noted above, Nakhleh and Samarapungavan (1999) studied the beliefs of young children about matter and found that a significant number did not think that there were minute aspects of common physical objects than could be seen with the unaided eye. For this reason, some children had difficulty understanding the concepts of magnification. Jones et al. (2003) studied young children who viewed magnified objects and how they saw beyond everyday perceptions. As students in their study worked closely with magnified objects, the students' perceptions changed with regard to knowing about shape and scale. Teacher E was describing a similar effect among some students in the enrichment class. Also, Nakhleh and Samarapungavan (1999) noted that young students tend to think of objects in terms of themselves, especially objects from the living world. Being able to see eyes and appendages of the insects gave Teacher E's enrichment students an insight into the biological similarities between large and small living things.

Post-interview 2006

Remarks group E-v-P6 1 of 2. Teacher E stated that in using the digital microscope, the students "[found that] even with the smallest little something, there is even more hidden that you don't see." The researcher noted that this statement was an important observation by the teacher. This telling statement, "with the smallest little something … even more hidden that you don't see" revealed to the researcher that the students were informing the teacher that they were seeing things more closely. Yet, even when they saw something more closely, there might be something that could be seen if looked at even more closely. Also, Teacher E noted that in using the digital microscope students could “look more closely and get a better view … it is not the only way, but [it is an important way to see].” The researcher noted that this statement followed the remark that the students were learning for themselves that looking more and more closely informed them and gave them a better view. The change noted here was with the students; they understood that although there might be other ways to see, looking more closely to get a better view, was an important way to see.

In teacher remarks about *knowing* with regard to the digital microscope, Teacher E spoke about how the students realized that with increasing magnification, more and more hidden things were revealed. Jones et al. (2003) studied school children who used powerful electronic microscopes and found that the students’ perceptions of progressively smaller objects vastly changed student perceptions of magnification and scale. Gerking (2003) reported similar findings about young students who used sophisticated and powerful telescopes. Studies like these showed that once students knew that there was an unseen world they adapted to it and soon learned that there were even more and more levels to which objects could be viewed in magnification. Jones et al. (2003) also noted that the microscope experience showed young children that microscopy was a way to get a better view of objects. This was a departure from the typical view of a young student who had not seen magnified objects, yet intuitively thought that objects tend not to have hidden features that might be seen with special equipment (Nakhleh & Samarapungavan, 1999).

Remarks group E-v-P6 2 of 2. Teacher E found that what the digital microscope "trained me to do is be more aware of my surroundings." The researcher noted that, in this case, the teacher was 'trained' by the digital microscope and knew to be more aware of the teacher's own surroundings. This denoted a change in the teacher's knowledge level and interest level. Now, this teacher believed that using the digital microscope could help someone to learn to be more aware of their surroundings.

In teacher remarks about *knowing* with regard to the digital microscope, Teacher E spoke about change in awareness about the nature of surrounding materials. Richardson (1990; 1991) addressed teacher change and attributed such change to the teacher's background and personal willingness to change based on prior experience. In this instance, Teacher E, an enrichment teacher, had the background and willingness to change personal perceptions about the surrounding materials based on experiences with digital microscopy. Teacher E was aware of the hidden microscopic world, but now using the digital microscope the teacher had personally experienced the microscopic world in so many ways.

Interview after first lesson 2004

Remarks group E-v-A4 1 of 3. Teacher E stated that in using the digital microscope, the students "learned a lot about focusing" and that in using the digital microscope, the students learned "by just doing it; they [the students] have a whole different understanding [now]." The researcher noted that providing students with the experience of using the digital microscope led to a whole different understanding (way of knowing) for students. In the first lesson, students learned by doing, which lead to a 'whole different understanding.' The change here was that in providing students with experiences with the digital microscope, the students learned by doing and then gained a different understanding than they had in using the standard light microscope. The teacher had the view that the digital microscope was not only a tool used in science, but it was also a tool that could help students gain a ‘whole different understanding’ through student inquiry.

In teacher remarks about *knowing* with regard to the digital microscope, Teacher E spoke about how students have a different understanding after having used the digital microscope for themselves in classroom inquiry. In discussing how students learn, Donovan et al. (1998) suggested a metacognitive approach where students learned by taking control of their own inquiry. Crowther (1997) suggested that a constructivist classroom worked best in science. In the constructivist classroom, hands-on activities where outcomes were not known took precedence. Teacher E used such an approach with the digital microscopes and student activities.

Remarks group E-v-A4 2 of 3. Teacher E found that in using the digital microscope, students would “look at [an object] and then say ‘I wonder what [it] would look like if I put it under there?’” The researcher noted that the students were interested in what would happen when they viewed the object under the microscope. The researcher noted that the words ‘I wonder’ and ‘what would it look like if I put it under there’ showed that the students were inquisitive. The change noted here was that the digital microscope caused the students to wonder and ask questions of themselves and then led them to try different ways to look at the object. The students were being driven by their own interest and sought out answers based on what interested them. The digital microscope provided a platform for the students to propel their own inquiry based on their own interest. The teacher gained an understanding of this inquiry by observing what the students did and said when they were looking at an object. This was an important observation by the teacher of student-driven inquiry made possible by using the digital microscope.

In teacher remarks about *knowing* with regard to the digital microscope, Teacher E spoke about how student inquiry using digital microscopy could lead to student wonder and discovery and the similarity of this to inquiry in scientific research. Roth (1994; 1999) wrote about student inquiry using representational devices and interactive classrooms where students could engage in dialogue with other students in the discovery process. Roth (1994; 1999) noted the emergence of scientific discourse during inquiry. Roth (1996b) noted how a central tool (here, the digital microscope) transformed the inquiry-based classroom and promoted knowledge diffusion. Teacher E described similar occurrences in the digital microscope lessons conducted and observed by the teacher.

Remarks group E-v-A4 3 of 3. Teacher E found that in using the digital microscope, students could “put [an object] under there, turn it, put something else under there, turn the dial, put something else under there, adjust it, focus it, change the magnification, going through that, just going through object after object after object; they [the students] understand it.” The researcher noted from these comments that the teacher made some very important observations. The teacher actually described what the students did as they viewed an object under the microscope. The students put the object under the digital microscope (the researcher noted that the teacher did not say where but was actually acting out where they put it), they turned it, they put something else under there, they turned the dial, they put something else under there, they adjusted it, they focused it, they changed the magnification, but – most importantly – 'they just went through object after object after object, and then the students understood it.' The teacher gained an understanding of what students did when they were looking at something closer and closer. The students informed the teacher by what they actually did. They went though a series of steps before they understood what they were seeing. The change noted here was that the teacher gained an understanding of what students did when they wanted to see an object closer and closer. The teacher's observation of the student became more detailed at this point.

In teacher remarks about *knowing* with regard to the digital microscope, Teacher E spoke about the sequence of events that students went through in order to 'understand' an object using digital microscopy and how they wanted to see closer and closer. Roth (1996b) discussed the knowledge diffusion that went on in a classroom community when students were permitted to conduct inquiry using a new tool. The new tool and student interaction and discourse about findings with the new tool transformed the classroom into a place of scientific learning. This learning led to understanding by students, the understanding referred to by Teacher E in this instance. In their innovative children's book, *Close Closer Closest*, Rotner and Olivio (1997) showed how images made by adults could show the way a child's mind would move in closer in a step-wise fashion on objects that a child is curious about. Interestingly, the book included images of some things that the students in Teacher E's class chose to observe, including faces, coins, and butterflies, perhaps indicating the universality of curiosity about these things. Rotner and Olivio noted that the purpose of their book was to show objects of interest, their perspective and scale, in three steps. Teacher E's students accomplished much the same thing with the digital microscope (using magnification steps of 10, 60, and 200 times), thus gaining a new understanding of perspective and scale.

Interview after lessons 2006

Remarks group E-v-A6 1 of 1. Teacher E stated that in using the digital microscope, students "know how things would change, [yet] just the view would change." The researcher noted that the teacher found that the students had come to a new understanding about what they are seeing through the microscope, which is the same image only a closer view. The change here was that the digital microscope enabled the students to understand that the actual object did not change only the view changed.

In a teacher remark about *knowing* with regard to the digital microscope, Teacher E spoke about students' understanding of magnified objects in digital microscopy. Jones et al. (2003) noted that after students worked with electronic microscopy; they thought of microscopy as a way to get a better view of objects. Experiences with microscopy allowed students to modify defective mental models (Greca & Moreira, 2000) that might hold them back, such as the impression that the digital microscope somehow made the object larger (as opposed to the concept of magnification).

Category – Object

Pre-interview 2004

About the digital microscope and its relationship to *object*, Teacher E anticipated that digital microscopy would allow students to find out that in order to "[see] a solid object you have to shine the light from the top." The teacher also predicted that students would "[discover that if the object is] transparent, you have to shine the light from the bottom." The teacher thought that in using the digital microscope, students would "look at salt and sugar and various things." And, the teacher anticipated that in using the digital microscope students would "study a lot of science activities like cells or plants or bugs or insects [and] all sorts [of] different things." The teacher added that in using the digital microscope students would "see the bugs and find the cells and different things."

Researcher summary (object) from pre-interview: In teacher remarks coded in the category *object*, Teacher E spoke about what the teacher expected that the students would see and do using the digital microscope. Specifically, the teacher anticipated that students would discover the way light passes or does not pass through objects and that students would be interested in looking at objects like salt, sugar, plants, and bugs. The teacher expected that science activities would be conducted by students using the digital microscope to observe objects.

Post-interview 2004

Remarks group E-vi-P4 1 of 5. Teacher E found that using the digital microscope "made things look a little differently." The researcher noted that students found out that things looked differently using the digital microscope. Teacher E discovered that in using the digital microscope, the students "reuse something that they saw in another project …, which they can't [study] if it is not digital." The researcher noted this was a change; the teacher was informed by observing students that they could 'reuse something they saw in another project.' The teacher mentioned that the students could not do this 'if it is not digital.' The teacher was aware that the students applied what they learned in a prior lesson and transferred this prior learning. Because of the capability of the digital microscope, students applied new imagery and findings to a project they were working on.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about transferring knowledge from another project. Several researchers, including Donovan et al. (1998), Bouillion and Gomez (2001), and Lovrich (2004) discussed the special importance of teachers drawing on pre-existing understandings of subject matter in the teaching process. Teacher E employed a similar strategy using the students' prior knowledge of similar technology.

Remarks group E-vi-P4 2 of 5. Teacher E found that in using the digital microscope, the students "noticed real quickly how it [the eye] would change according to the light and different things like that [while using the microscope in hand-held mode]." The researcher noted that the teacher discovered that the students found out how the human eye changed under different light sources. The researcher noted that this happened while the digital microscope was in the hand-held mode. This feature of the digital microscope made this observation possible and the students discovered this for themselves. The teacher observed that the students found this out 'quickly.' The change here was that the students were able to see their own eye using the hand-held mode of the digital microscope and the teacher was informed by what the students selected to observe and the aspects of that object that interested them.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about what interested students and how quickly the students learned about what interested them. Roth (1994) discussed how quickly students communicated their interests and discoveries when they were all working with a representational device. In using such a device, Roth (1994) noted that efficient communication occurred and all participants learned from the experience. Teacher E discovered that the enrichment students all learned very quickly through efficient communication about an object (in this instance, the human eye) that they were interested in studying.

Remarks group E-vi-P4 3 of 5. Teacher E found that in using the digital microscope, the students "get interested in looking at buttons or fabric or just looking at a plain piece of fabric." The researcher noted that the teacher observed how students were interested in things they were wearing. Teacher E also stated that in using the digital microscope, the students would "video their hair, not just take pictures of it, but [show how] it moves, it waves, and 'your hair is too short and it doesn't wave.'" The researcher noted that the teacher found out how the students used the video function of the digital microscope as well as the picture function to observe the difference in hair strands. The researcher noted that the teacher was informed by what the students said. The students were using the language that they were accustomed to in order to describe something that was new to them. The researcher noted that 'describing something in their own words' was an important observation. This observation showed a change in how students 'see' something in a different way. They did not have the vocabulary to describe what they are seeing scientifically but they use their own describing words. The researcher noted that taken in context this was a connection or a leap in awareness and discovery.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about what students observed during inquiry, student discourse during inquiry, student terminology or words used to describe, and the progression of learning. Roth (1999) noted that students came to a phenomenological understanding of objects and materials studied when they were allowed to do inquiry in an environment of scientific discourse among themselves. In such a classroom, Roth (1994) noted that students engage in what he called scientific talk using words they know and other things like gestures and body language. Roth (2001a) observed that students would continue such talk until a more stable language for description of what they were seeing emerges. Roth (2003) noted that continued discourse among students, who formed a community of practice in the classroom, allowed for cognitive development of the participants. Roth (1996b) pointed to actor network theory to explain how connections or breakthroughs by one student or a group of students propagates through the learning community. Roth (1996b) called this knowledge diffusion, which he described as being was aided and transformed by introduction of a new learning tool. In this instance, the learning tool was the digital microscope.

Remarks group E-vi-P4 4 of 5. Teacher E noted that in using the digital microscope, the students observed that "the object didn't change, but you are just getting closer to it … and how many times closer." The researcher noted that this was a very important observation, which was communicated by the students who informed the teacher. The teacher was informed that the students knew the object was the same as the enlarged image that they were observing.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about student perceptions regarding the object viewed versus the enlarged image. Jones et al. (2003) reported on the change in perception of young children regarding scale and magnification after they were involved in inquiry-based lessons using electronic microscopy. In this instance, the students gained knowledge in this area and informed the teacher of their understanding.

Remarks group E-vi-P4 5 of 5. Teacher E found that in using the digital microscope, the students could “study fruit flies,” “count this or that,” “study money,” or, more specifically, “count how many scales are on this [animal]” and “count how many sides or shapes [a thing has].” The researcher noted that the digital microscope was used to study things like fruit flies and currency, but also it was used to count things and study shapes of things. With regard to the latter, the researcher noted that the digital microscope lessons included a mathematics aspect as well.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about the many objects that students might observe and what they might do during investigations with the digital microscope. In writing about teacher change, Richardson (1990; 1991) noted that teachers were generally open to new inquiry in proportion to their background in related areas. Teacher E had previously conducted lessons on the items mentioned and had worked with bringing mathematics into some of those lessons. Therefore, in speaking about what the students could do, the teacher brought those things into the discussion. The students’ experiences and objects seen (insects and coins) were much like those shown in the popular books *Close Closer Closest* (Rotner & Olivo, 1997), which explored students’ views of perspective and scale, and *Money Money Money* (Parker, 1995), which explored the fine details of engraving on currency.

Post-interview 2006

Remarks group E-vi-P6 1 of 9. Teacher E stated that in using the digital microscope, the students “put it on their eye-ball; that was one of their favorite things, because – I think – you do not see your own eye.” The teacher added that the students felt that the eye “is weird looking when you get really close.” The researcher noted that

Teacher E found out one of the students' favorite things was looking at their own eye and that they found that it was 'weird looking' when you get really close, something they were interested in seeing up close, and something they were familiar with and curious about and something they would not be able to magnify outside of class.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about student interest in looking at the human eye using digital microscopy. As noted above, Roth (1994) discussed how quickly students communicate their interests and discoveries when they were all working with a representational device and studying something of great interest. Teacher E mentioned the human eye in the previous interview and mentioned again here that the enrichment students all learned very quickly through efficient communication about an object (in this instance, the human eye) that they were all interested in studying.

Remarks group E-vi-P6 2 of 9. Teacher E stated that in using the digital microscope, the students started "putting it on your arm – the hairs on your arm – how interesting that was to them … and then one person's arm to another person's arm … the hair is longer, the hair is darker, the follicle, … the difference in skin." The researcher noted that the teacher was informed by what the students were saying as they observed their own arm and compared it to other students. This comparison led them to make some unique observations. One student started looking at the arm hairs which led to other students being interested and observing and comparing. The comparisons led to the discovery that not all arm hairs are the same. Using the digital microscope allowed the students to compare using the monitor and the hand-held mode of the microscope. The students were engaged because they were interested in something that was new and unusual, and this led to a lesson that was driven by student interest and discourse. The change here was that the digital microscope helped the teacher learn what interested students and what they wanted to look at using the microscope. Also change was noted here in that the digital microscope helped the teacher to know about what interests students and what they do and say when they are interested. In some related comments, Teacher E discovered that in using the digital microscope the students ‘looked at fingerprints and then they would look at their own and say it looks kind of the same.’

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about observing the differences between objects, especially things of interest like hair and skin. Roth et al. (1999) noted the interaction of focal artifacts (things being studied) and social interconnections in the inquiry-based classroom. In the instance of students’ skin and hair, there is a convergence of the focal artifact and the social interconnection that makes these objects understandable sites for student investigation. Teacher E observed that this was so in the digital microscope lessons.

Remarks group E-vi-P6 3 of 9. Teacher E found that in using the digital microscope, the students “look at the money and see the things that you don’t … the micro-print [really surprised] them.” The researcher noted that the teacher was informed by the students that they were very interested in seeing ‘money’ (currency) and that they noticed little things on the paper, like the ‘micro-print.’

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about students being interested in things not seen. Regarding fascination with the unseen world, Jones et al. (2003) reported changes in interest level in nano-scale features among young children after they were involved in inquiry-based lessons using electronic microscopy. Jones et al. (2003) noted that student inquiry was driven by the discovery of finer and finer features on objects being examined. In this instance, the students gained knowledge about fine features by looking at the fine details within paper currency (see Parker, 1995).

Remarks group E-vi-P6 4 of 9. Teacher E discovered that in using the digital microscope, the students "[looked at] a sample of money from their home country or where their grandparents or where their parents are from … and so, it was like cross-cultural kind of things going on." The researcher noted that this was a very important observation where the teacher was informed by what the students did. This was something unexpected. After first studying U.S. currency, some students brought in other types of currency, which showed they were interested in seeing it using the digital microscope. The lesson changed from one of looking at currency close up to a cultural or history lesson. The researcher noted that the lesson involved science, social studies, and history.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about the high level of student interest causing the students to bring in currency from outside the U.S. to examine in class after having looked at U.S. currency with digital microscopy. Open-ended, or divergent, questions have been used in inquiry lessons for some time (Carin & Sund, 1970) and were most effective because there were a variety of responses and correct answers, which further stimulated discussion. The researcher noted that these sorts of questions affected the currency lessons. As noted above, Jones et al. (2003) reported changes in interest level in nano-scale features among young children after they were involved in inquiry-based lessons using electronic microscopy. Jones et al. (2003) noted that student inquiry was driven by the discovery of fine features on objects being examined. In this instance, the students gained knowledge about fine features by looking at the fine details within U.S. paper currency and then sought out similar details on non-U.S. currency brought from home. The interdisciplinary connections made by the teacher and students were unexpected and the teacher was 'surprised' by them. Rahm et al. (2003) noted the main characteristic of authentic science was the emergent property of the work. Here, the discovery of social studies and history in connection with the science of microscopy was entirely emergent (not anticipated by the teacher).

Remarks group E-vi-P6 5 of 9. Teacher E found that in using the digital microscope to study currency, the students "[understood] just what it is made of – and why it is not paper – it is linen and cotton … well, that [really surprised] them because they thought it was paper, it was [made from] wood, but [now they know] it is not even paper." The researcher noted that the lesson on money caused the students to be puzzled by what they thought was one thing but turned out to be something quite different when they saw it up close. The digital microscope made this possible and also informed the teacher of what students did and said when they were curious about something. The change here was that the digital microscope allowed the students to not only see an object such as currency but also to have the students question what they were seeing when they looked at the object up close or under greater magnification.

In addition, Teacher E found that in using the digital microscope to study currency, the students "look at the inks, and look at the printing, and what goes into that … and then there is – in the middle of it – there is a little security thread … it is in the middle of it, it is not on the front, it is not on the back." The researcher noted the detail that the teacher was using when describing what happened in the lesson. The researcher also noted that the students observed inks, printing, and 'what goes into it,' but were particularly attentive to the 'little security thread…in the middle of it.' The researcher noted that the teacher was very involved with what the students were seeing and saying to each other and was surprised at what was said. The change noted here was in the teacher's detailed observation and the teacher's involvement with what the students were looking at and what surprised them.

In teacher remarks about *object* with regard to the digital microscope, Teacher E described what was in effect open-ended, student-driven inquiry and the excitement and surprise among students when discrepant findings did not conform to their preconceived ideas. Donovan et al. (1998) noted that students came to the classroom with preconceived ideas about the world. Much of learning would build on these preconceived ideas, which would change with new experiences and information. In constructivism, when something new is experienced, it is internalized based on prior understandings (Crowther, 1997). In this instance, students thought that 'paper money' was just that – paper that was worth a stated amount of money. The students were surprised, in other words, their view of money as paper was changed, when they saw that money was not really made of paper. For Roth (1999), this would be the phenomenological understanding that the inquiry-based classroom should elicit. The students being 'surprised' by what they discovered at a fine scale on U.S. currency was an example of the emergent effect. As noted previously, Liem (1987) and Appleton (1996) wrote about constructivist aspects of teaching about discrepant events. However, the discrepant events in this instance emerged unexpectedly from the lesson. Teacher E noted how the students were faced with the cognitive conflict of selecting magnifications and the students used social interaction to resolve their questions about what was happening. Teacher E's students were conducting their own inquiry in the digital microscopy lesson. In addition, Liem (1987) wrote about the importance of excitement in inquiry lessons. Teacher E noted the level of excitement and how this positively affected the lessons.

Remarks group E-vi-P6 6 of 9. Teacher E stated that in using the digital microscope to study currency, the students said "look how this is drawn," and "you know the way these scrolly-looking leaves [appear], 'well, you know, I saw that on so-and-so building or I have seen this before.'" The teacher also found that students "will call out, 'oh, we studied that in art, it is a fleur-de-lis.'" The researcher noted that the teacher revealed what the students said during discourse, such as 'I saw that on that building' or 'I have seen this before.' The researcher noted that 'the students called out' things like 'we studied this in art' and 'I have seen this before.' The students' use of this kind of discourse was very important in the lesson, in discovery, and in sharing with other students. The students described what they were seeing in their own words such as 'scrolly-looking leaves' and also 'compared to other lessons' such as 'we studied this in art' and 'it is a fleur-de-lis.' The change here was that the students were relating to other experiences using the digital microscope and have become more detailed in describing what they are seeing.

In addition, Teacher E found that in using the digital microscope to study currency, the students "looked [very] closely at a dollar bill … and it is like … 'you know, the thirteen colonies,' to which the teacher remarked 'okay, that is a significant number' in our country." Teacher E stated that in using the digital microscope with currency, the students "notice something [and say] 'oh, I have seen that before somewhere,' I know that I have seen it before' … and then it gets their curiosity … they will go out and find out where they have seen it before." The teacher added that "somebody brought in a two-dollar bill … and somebody brought in … [other types of currency] … we have so many different cultures around here." The teacher also added "they wanted to bring in money, you know." The researcher noted that the students first observed something, reflected back to some prior experience, that stimulated their curiosity, and finally they went and found out where they had 'seen it before.' This process brought in something from their own experience to share with others. The teacher was informed by the dialogue of the students and from what they brought in to the classroom to share.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about student discourse in the classroom, students' prior knowledge, and student words for what they were seeing. Roth (1994; 1999) found that student discourse, including speaking, gesturing, and body language, were of great importance in the emergence of understanding in a science classroom. Roth (2003) emphasized the need for students to scaffold their prior knowledge into a present understanding. Several other authors, including Crowther (1997) and Donovan et al. (1998) have made this point as well. Roth (1994; 2001a; 2003) noted the importance of student scientific talk, which starts out using common terms and gestures that the students all understand. White and Fredrickson (1998) and Pearce (1999) described an 'inquiry cycle,' which is a process building upon prior knowledge, observation, and testing by the student during inquiry. In the course of this lesson, Teacher E uncovered these relationships and spoke of them in this part of this interview.

Remarks group E-vi-P6 7 of 9. Teacher E found that in using the digital microscope to study currency, the students really were immersed in the subject and this was somewhat different from “the first lesson, way back when, when we were looking at just a random set of objects.” The teacher reflected on the fact that the study of currency had significantly engaged the students, to some extent, even more than natural objects. The change here was in the lesson plan which included an investigation of currency, which was different from a ‘random selection of objects’ in previous lessons.

In a teacher remark about *object* with regard to the digital microscope, Teacher E spoke about how looking at U.S. currency had engaged student interest more than looking at various objects. Nakhleh and Samarapungavan (1999) studied beliefs among young children regarding the objects in their world. They noted that young students tend to think of objects in terms of themselves. Teacher E found that the fine detail and structure of U.S. currency held a particular fascination for young students.

Remarks group E-vi-P6 8 of 9. Teacher E stated that in using the digital microscope, the students have “studied regular salt … I just never knew how different it really looked [under the microscope] … I knew that sugar and salt [are] different, because you are told they are different … and they taste different … but when you get really up close, they look different.” The teacher added “but then to make the crystals and watch them grow, you see pictures of it, but until you see it go ‘ching’ and shoot off as it dries … and [that] happened really quick after we finally got it going.” The researcher noted that the teacher was also personally intrigued by how different the objects in this case salt and sugar looked up close. The teacher explained what happened and describes the process of the crystals growing. The change here was that the teacher became engaged in the investigation along with the students, and this was not anticipated by the teacher in the pre-interview.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about how much the teacher was involved with the students in the inquiry process. Rahm et al. (2003) wrote about authentic science as an emergent property of partnerships. In this instance, the partnership was between the teacher and the students. Roth (1994) observed that efficient communication occurred when the student group had access to the representational device (here, the digital microscope) and the device spurred authentic discourse. Teacher E described something similar here.

Remarks group E-vi-P6 9 of 9. Teacher E found that in using the digital microscope, the students “studied the Epsom salt [crystals].” Teacher E added that “I never [knew] what it really looked like … because I [never got] close enough [to see individual crystals] … I have no problem at all understanding that the Epsom salt [crystal] is longer … I mean, that you have some of them that are more square [like salt], or more octagonal shape, or … that they are different, it is not just white, chunky mounds of sugar or Epsom salt or what ever it is that you are using.” The researcher noted that the teacher learned through the experience of the students doing the lesson on Epsom salt crystals. The teacher and the students never knew what Epsom salt really looked like before using the digital microscope. The researcher noted that the teacher was informed by what the students said and did when they got close enough with the digital microscope. The salt was not ‘just white, chunky mounds of salt or whatever you are using.’ The teacher stated ‘because I did not get close enough,’ but when the students did it revealed what a student or teacher might see. The researcher noted that the teacher became a part of the learning experience and also became a learner so that in sharing the experience the teacher could be informed what the students might be seeing when they got close enough. The teacher informed the researcher that when you get close enough ‘you have some of them that are more square, or more octagonal shape’ and some ‘are different, it is not just white, chunky mounds of sugar or Epsom salt or what ever it is that you are using.’ The change here was that the digital microscope allowed the teacher and students to get a closer view of the salt crystals that revealed various shapes, which the teacher and students found very interesting. The teacher noted that the students were able to study the salt. The researcher noted that the teacher was able to be more detailed in what happened when the students examined the salt. The salt was no longer just white, chunky mounds. The students were able to detect a variety of shapes that were different.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about discovery during inquiry along with the students. In writing about teacher change, Richardson (1990; 1991) noted that teachers are generally open to new inquiry in proportion to their background in related areas. Teacher E had previously conducted lessons on growing crystals, but not Epsom salt, therefore her interest was understandable. Several authors, including Rahm et al. (2003), have written about authentic science as an emergent property of partnerships. In this instance, the partnership is between the teacher and the students. Teacher E described emergent aspects of this inquiry, some of which the teacher was directly involved.

Interview after first lesson 2004

Remarks group E-vi-A4 1 of 4. Teacher E stated that in using the digital microscope, the students "watched crystals grow." In this brief comment, the researcher noted that this activity was part of the first digital microscopy lesson and that they were observing a process that was made more easily observable by the digital microscope. The change noted here was that the students were able to observe the process of crystals growing, which was not possible or not achieved in previous lessons using the light microscope.

In a teacher remark about *object* with regard to the digital microscope, Teacher E spoke about watching crystals grow. The activity of crystal growing, which was an activity based on the concept of small-scale change over time in development of natural materials, was one of the most basic types of recommended classroom scientific inquiry (Lawless and Rock, 1998).

Remarks group E-vi-A4 2 of 4. Teacher E stated that in using the digital microscope, the students would "look at a mole on your face, or a freckle, [they] enjoyed the eye, [they] wanted to look up guy's noses, and [they] wanted to look at girl's eyes and hair." The researcher noted that the teacher noticed there was a difference in what the boys and the girls chose to look at when they were looking at their features. The researcher noted that the students looked at things that they were curious about and the digital microscope's hand-held mode enabled them to look at these features, which was not possible with the standard light microscope. The change noted related to what the teacher found out about students' interests. Because the digital microscope's hand-held mode allowed the students to place the microscope on what they were interested they did so in various ways. As a result, lesson plans were changed to include looking at objects that interested the students.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about student interests and the researcher noted changing lesson plans according to student interests. In writing about teacher change, Richardson (1990; 1991) noted that teachers are generally open to new inquiry approaches in proportion to their background in related areas. Teacher E had previously conducted lessons on a variety of topics, but was open to changing the focus of inquiry in this instance to capture students' attention and imagination.

Remarks group E-vi-A4 3 of 4. Teacher E stated that in using the digital microscope to look at coins, the students "found on the new quarters some little mark," "[looked at] the words [on a coin]," and "looked at the mint marks," "looked at scratches in a coin," and "saw it [the coin] a whole different way." The researcher noted that in using the digital microscope the students could see an object, in this instance a coin, in a whole different way. The researcher noted that in being able to see coins closely; the students were able to discover things that they were not aware of before. They found 'some little mark, mint marks, and scratches.' The change noted was that the digital microscope allowed the students to find a variety of things on a coin that they had never noticed before. The teacher observed that the digital microscope helped the students see in a whole different way. The 'different way' that the teacher spoke about was actually a closer view of an object. When students looked at coins closer they saw 'some little mark, words, mint marks, or scratches,' which were physical features but when compared to other coins led to more detailed observations. Also, the findings led to other investigations such as what were mint marks, where do the scratches come from, what wears down coins, what do the words mean, what about the date, etc. The ability to see objects more closely led the students to learn about other things that began with the discovery that there are interesting things on something like a coin. The change here was that the teacher learned not only what was on a coin but what interested the students that were found on a coin.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about the many observations that students made about coins and their condition and the directions that those observations lent to student inquiries. As with the investigations on U.S. currency, the students found many connections to the study of U.S. coins using digital microscopy. As noted previously, Rahm et al. (2003) wrote about authentic science as being an emergent property of inquiry. In this instance, the emergent properties of the inquiry were the many questions and many connections that students developed while examining the surfaces of coins using digital microscopy.

Remarks group E-vi-A4 4 of 4. Teacher E stated that in using the digital microscope, the students could "see how [the doily] is latched together and you can see the weave of it" and "looking at ribbon … or fabric to see that it is not just a piece of fabric, that it goes down to [individual threads]." The researcher noted that using the digital microscope students could see a lot closer when they examined fabric or ribbon. They were able to see the latching and the weave and saw the difference between a ribbon and fabric. The change noted here was that the students could see a lot closer and could see the weave of a fabric or ribbon. The students were not just seeing fabric when they used the digital microscope but they were able to see the make-up of the fabric and how it was ‘latched together.’ The teacher anticipated in the pre-interview that the students would look at fabric, but now the teacher has become more specific in describing fabric including the ‘weave’ and the individual threads.

In comments about *object* with regard to the digital microscope, Teacher E spoke about seeing more clearly the finer structure of a common object, in this instance a doily. Nakhleh and Samarapungavan (1999) noted that young students do not necessarily have an understanding that there may be a finer or more detailed structure to macroscopic objects. One of the best ways to show that this is so involved inquiry using the microscope (Bellis, 2004). In this lesson, Teacher E employed this method with success.

Interview after lessons 2006

Remarks group E-vi-A6 1 of 4. Teacher E found that in using the digital microscope, the students “study … money; we have done the coins before, but we had not done the bills … that was great fun; that was probably our favorite … some of the older ones are even more fun to look at because of the micro-print and stuff … but we have spent [lots of time on this].” Teacher E stated “oh, I cannot tell you [how excited they were] – all the kids were like ‘*I’m showing my dad!*’” The researcher noted that when the students examined money – coins and then currency – the teacher was informed by the students that they were interested and excited by what they were seeing. The teacher noted it ‘was great fun’ and ‘probably our favorite’ activity. The researcher noted that the statement ‘I’m showing my dad!’ helped the teacher know that the students were interested. The teacher learned by the students examining the bills and finding the micro-print, which had never been looked at before in their class, and from the students’ discourse. The change here was that the teacher learned that the students were very interested in studying currency. This was not anticipated by the teacher in the pre-interview. The teacher also learned that this study was something that the students wanted to share at home.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about the interest and excitement level of the student and how that related to the success of the inquiry activity. Bell and Linn (2000) pointed out the social aspects of successful inquiry, including the need of many students to express their excitement of discovery. Roth (1994; 1999) wrote about the important role of discourse in the inquiry classroom in order to have knowledge diffusion. Barab and Hay (2001) pointed out that students enjoy a sense of ownership of findings based on inquiry lessons. And, Jones et al. (2000) referred to the need for conversation space in forming concepts during and after inquiry. Liem (1987) wrote about the great importance of excitement in science inquiry. In this instance, excitement promoted discourse between teacher and students and among students in the classroom and discussion later on and at home. Teacher E noticed that students were excited and this provided feedback to the teacher that the lessons were effective.

Remarks group E-vi-A6 2 of 4. Teacher E found that in using the digital microscope, the students studied “butterflies … [so] the kids have been bringing me broken wings, and dead butterflies … we are still working on it … we are getting it ready … we have several weeks to go … the teachers had the butterflies and they hatched [and we looked at them].” The teacher also added that the students were so fascinated by digital microscopy that “it doesn’t matter what it is” that they are studying. The researcher noted that the students brought in things that interested them such as broken wings and dead butterflies. The change here was that the teacher discovered that the students found a variety of things to look at including things that were unusual. In addition, the teacher collaborated with other teachers by sharing a lesson on butterflies. The teacher built on the lesson that was started in another classroom, and then the enrichment class used the digital microscope to continue building on what the students were already studying.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about students bringing in things to study using digital microscopy, including butterflies, and the teacher's sharing lessons with others. As mentioned earlier, Nakhleh and Samarapungavan (1999) studied beliefs among young children regarding the natural world. They noted that young students tend to think of objects in terms of themselves, especially objects from the living world like butterflies. Being able to see eyes and appendages of the insects gave Teacher E's enrichment students an insight into the biological functions of parts of the butterfly and by extension, other insects as well. Teacher E's 'sharing lessons' was a voluntary activity among fellow professionals, which was a type of collaboration (Gosselin et al., 2003) reported by the teacher.

Remarks group E-vi-A6 3 of 4. Teacher E found that in using the digital microscope, the students "work with manipulatives … some of the kids just learn better that way." The teacher also stated that the digital microscope helped the student "see shapes." The researcher noted that the teacher revealed a belief about how children learn. By using and working with manipulatives, some of the students learn in a better way. The researcher noted that the teacher's reference to 'manipulative' meant the digital microscope. The digital microscope could be manipulated by the students in the hand held mode. In this way, the students examined their face, eyes, hair, nose, or – when the microscope is in its stand – they focused on what interested them. Using the digital microscope, students saw things closer and discovered things that were not possible to see with only the eye. The change here was that the teacher found out that the students work better with manipulatives which was not mentioned in the pre-interview.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about the digital microscope as a manipulative device. As noted previously, many educational researchers, including Donovan et al. (1998) who wrote a U.S. Department of Education-sponsored volume (*How People Learn*), have expressed the view that hands-on learning environments where students can take control of their own learning and conduct inquiry are the best for science and other classrooms. Teacher E was expressing the view that digital microscopy was a very effective means of hands-on learning.

Remarks group E-vi-A6 4 of 4. Teacher E stated that in using the digital microscope, the students "do our money unit." The teacher added "we were doing art for the design on the money, math because of the money, and the values of money and the different things we were talking about there … technology with the microscope and all the aspects of using the computers and history because they were learning a lot about history about what they would learn about what was on the bills." The researcher noted that the teacher mentioned more in this regard than in the pre-interview. The teacher found that in one lesson on currency, the students covered art regarding the design and mathematics regarding the value of money and other things that were found on the currency. In addition, technology accompanied the digital microscope as did all aspects of computer usage and history of what was on the currency bills.

In teacher remarks about *object* with regard to the digital microscope, Teacher E spoke about many curriculum connections using digital microscopy. That the many interconnections of scientific inquiry should be effectively used in education made clear by comments in many publications, including Lane (1996b) who wrote about this in the National Science Foundation-sponsored report (*Shaping the Future*). Teacher E was making those connections in newly discovered ways using digital microscopy.

Category – Seeing

Pre-interview 2004

About the digital microscope and its relationship to *seeing*, Teacher E anticipated that digital microscopy would "give a different view" and that the students would be able "to see things up close." The teacher added that the students would be able "to see individual parts," "view items," and that the students would be able "to see [that an object] is pretty." The teacher predicted that the students would be able to "see it in different ways" and noted that students might "almost lose what the object is entirely." The teacher also expected that students would be able "to see it far away and then see it closer, closer, closer" and they would be able to "see what the difference was between 10 times and 60 times and 200 times and what does that mean."

About the digital microscope and its relationship to *seeing* specific things, Teacher E predicted that students would want "to look at their face, their eye, body part, finger, mouth, [or] 'shine it on my teeth.'" Also, the teacher anticipated that the students would "pick up a penny, put it under, [and] see it." Further, the teacher anticipated that in using the digital microscope, the students would be able to "see a small area on a coin," "see [that] sometimes you can't see the [fine details without magnification]," "look up close at coins." The teacher also anticipated that students would be fascinated with objects by "being able to get closer to them."

About the digital microscope and its relationship to *seeing* during lessons, Teacher E predicted that in using the digital microscope, the students would be able to "be interested in seeing … when you are getting closer up on an object." Also, the teacher anticipated again that the digital microscope would "give them [the students] a different view," would be able to "look in a different way," and would be able "to see the results of [some experiment] like – if we are making crystals."

Researcher summary (seeing) from pre-interview. In teacher remarks coded in the category *seeing*, Teacher E anticipated what the students would see and do using the digital microscope. Regarding the digital microscope and seeing, the teacher predicted it would a different view and students would be able to see small parts of objects and in different ways, including understanding magnification better. Regarding seeing specific things, the teacher mentioned students viewing parts of the body, and coins. Regarding seeing objects during lessons, the teacher mentioned student interest being aroused by looking in different ways and that students would see the results of experiments like crystal growing in a new way.

Post-interview 2004

Remarks group E-vii-P4 1 of 8. Teacher E found that in using the digital microscope, the students "understand they saw a lot of things, like [on] a coin, that they didn't recognize was there and they said 'oh, look you can see this or that' and the other." Teacher E added that "on older coins, there would be scratches or it would be worn down and you could look at a new coin and see the differences and to think the other coin looked like this at one point." The researcher noted that the teacher found the students understood a lot of things about coins after they looked at the coins using the digital microscope. The researcher noted that the teacher related what the students said 'oh, look, you can see this or that' about things they had not noticed before. The researcher noted that the teacher was informed by what the students did and said. The students saw scratches and worn-down scratches on older coins. They looked at the differences and found 'that other coins looked like this at one point.' The researcher noted that this was an important observation by the teacher and showed that in comparing the newer coins to older coins by their own investigation they were able to make a connection in noticing the difference between the coins. Then, they came up with an explanation that at one time the older coin looked like the newer coin, but something happened over time. The students informed the teacher that what they observed was that the coin became worn down, it had scratches that also were worn down, and these were things that they did not notice without using the digital microscope. The researcher noted that the teacher was informed of this new understanding through the students' own investigations of an object, the coin, that even though they had looked at coins many times before they were not aware nor did they see the differences, in this instance, between older and newer coins. Faced with this, students were able to discern that something must have happened to the older coins to have them look so different from the newer coins. Then, the students were able to see the scratches, the worn scratches, the differences between new and old, and were able to infer from their own observation that 'oh, look, you can see this or that,' which was shared with other students to 'to think the other coin looked like this at one point.' The change here was that in the process of 'seeing' the students gained an understanding of aspects of the coin that were not anticipated by the teacher or the students. The observation of the coin using the digital microscope led to an investigation to compare other coins and then compare the results. Another change here was that in this lesson of observing a coin became an investigation leading to discoveries driven by what the students selected to see and what they found interesting.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about the importance of student discourse in inquiry-based learning. As noted previously, Roth (1994; 1999) wrote about the important role of discourse in the inquiry classroom in order to have knowledge diffusion. Roth (1999) referred to the phenomenological understanding that students acquire by interacting with other students and the materials to be studied. Roth (1996b) showed how knowledge diffusion occurred in the inquiry classroom when a new tool (here, the digital microscope) was introduced into the learning process. Seeing unexpected marks on coins was a discrepant event for students, which was a cognitive conflict for them (Appleton, 1996). This conflict emerged unexpectedly from the lesson and was resolved by social discourse using the digital microscope. Teacher E noted these sorts of processes and effects in describing the students' inquiry about coins using digital microscopy.

Remarks group E-vii-P4 2 of 8. Teacher E found that in using the digital microscope, the students were able to "see their fingers, their fingerprints, their mouth, their ear, their nose, their eye." The researcher noted that the teacher had anticipated the students might be interested in looking at their facial features but did not mention the ear or fingerprints. Teacher E also noted that in using the digital microscope, the students were able to "notice [that] ... it [fabric] has little loops in it." The researcher noted that the teacher learned how the student looked more closely by seeing that ‘the fabric had little loops.’ This informed the researcher that the teacher was able to see what the student was seeing by looking at the monitor showing the magnified object and was able to listen to what they said about what they were seeing. This description and discourse were important to the observation and connected the seeing with a verbal description and provided more information to the teacher than just seeing and sharing what was on the monitor but also seeing and hearing what the student was sayin*g* about the magnified image. The change here was the teacher’s knowledge of what students were interested and what they saw when using the digital microscope, as conveyed through discourse between the students and observation of student behavior and interaction.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about what the students were doing and saying and how the teacher was informed of this. As noted previously, Roth (1994; 1999) wrote about the important role of discourse and gestures in the inquiry classroom in order to have knowledge diffusion. Teacher E noted that in using digital microscopy the students engaged readily in discourse and used gestures to make their points about the history of the coins being studied.

Remarks group E-vii-P4 3 of 8. Teacher E found that in using the digital microscope, the students were able to “see things up close” and “take it [the microscope] off [its stand] and manipulate it and ... change the level of magnification and ... hold it in their hands.” The teacher also mentioned that the students were able to “enlarge an item” and “see what items can [be seen] at different magnification levels.” The researcher noted that the teacher was describing what the students did (‘see things up close’) when objects were too large to place under the objective. The change here was in the kind of objects that the students would observe now using the hand-held mode of the digital microscope, which gave the teacher further insight into what students were interested in, and how students observed objects that were larger and that needed to be observed using the hand-held mode of the digital microscope.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about student actions in trying to observe objects of size. Roth (1994; 1999) wrote about the important role of discourse and gestures in the inquiry classroom in order to have knowledge diffusion. In a related study, Roth (1996b) observed what happened when a new tool was introduced into an inquiry classroom. This new tool transformed the classroom and students engaged in discourse and gesturing in order to communicate what the tool was helping them understand. Here, the digital microscope tool was being examined by the students and they discovered the uses of the hand-held mode when dealing with objects of size. This mode of using the tool was communicated through the group, in a manner much as Roth (1996b) described. Teacher E described a useful tool effect, much as Roth did.

Remarks group E-vii-P4 4 of 8. Teacher E stated that in using the digital microscope, the students were able to "find things to look at even when I [the teacher] was not directing them [the students]" and "even without me [the teacher] telling them what they [the students] needed to look at, they were finding things." The researcher noted that the teacher was not the only person that brought items to be looked at using digital microscopy. Students' bringing many things to be viewed was not anticipated by the teacher. The researcher noted that the students wanted to look at objects that they were interested in and did so without prompting by the teacher. This showed that the students were interested in seeing things and were curious. The actions of the students informed the teacher that the digital microscope aroused the curiosity of the students. It prompted them to look for things on their own initiative that would be able to be observed using the digital microscope. The students looked for items, found items, selected suitable items, and brought them in. The digital microscope lesson that the teacher used informed the teacher what students do when they are curious about something. The change here was that the teacher found out that the students wanted to look at things that *they* selected.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about how students brought objects to be observed without being told to do so and the high level of curiosity evident in the students. Krajcik et al. (1998) found that young children could be very helpful in designing investigations and providing materials for those investigations, especially when the students were highly interested in the inquiry. Barab and Hay (2001) pointed out that students enjoyed a sense of ownership of findings based on inquiry lessons and that their participation, for example bringing materials from outside, increased this sense of ownership. Teacher E noted a similar effect of the lesson upon the enrichment students.

Remarks group E-vii-P4 5 of 8. Teacher E found that in using the digital microscope, the students were able "to see that there are shapes that occur in nature." The researcher noted that the digital microscope connected the learning to the natural environment and comparison of shapes. Teacher E discovered that in using the digital microscope the students were able to "see [that there] really is something that is a true part [and therefore see] why it is not man-made or hand-made." The researcher noted that the students were able to connect with the shapes they were observing. The researcher also noted that the students' ability to make a decision using the digital microscope and to see if something was man-made or hand-made informed the teacher by what the students were doing and saying. Students were talking about seeing an object and looking for shapes that occurred in nature, so the students were able to 'see that something is a true part of what it is, not hand-made or man-made.' The change here was that by listening to students' discourse the teacher was informed about what the students were seeing and what interested them.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about students' ability to interpret what they saw using digital microscopy and students' communicating with the teacher about what they saw and what interested them. As noted previously, Roth (1994; 1999) described the important role of discourse and gestures in the inquiry classroom in order to have knowledge diffusion. As the enrichment students engaged in discourse about their findings, the teacher was informed of their understanding of the lesson. Roth (2003) also wrote about discourse and cognitive development of students engaged in inquiry activities. Teacher E was a part of this process and observed as the students interpreted through observation and discourse what they were seeing.

Remarks group E-vii-P4 6 of 8. Teacher E found that in using the digital microscope, the students were able "to see things that they [the students] have seen millions of times" but not up close. The researcher noted that the digital microscope allowed the students to see what they had not seen before on common objects. The teacher added that “the students see that there is a mouth on it” or “see the claws or the pincers or the stinger [and say] – ‘oh, that’s why it hurts.’” The researcher noted that the students were able to make these insights by using the digital microscope to make the connection, for example, seeing the stinger and then saying ‘oh, that’s why it hurts.’ The researcher noted that the students informed the teacher about how they made a discovery by what they were doing and saying. The digital microscope in this case aided in discovery and in relating the object to a prior experience. In this way, students came to an understanding. The change here was in the ‘seeing’ of an object that was familiar to the student but afterward the student saw things in a different way.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about students making a connection to a prior experience (in this instance, being stung by a bee) and observing something related (in this instance, a bee’s stinger) and making a connection (for example, the ‘aha moment’). Roth (2003) wrote about discourse and cognitive development of students engaged in inquiry activities and the importance of scaffolding with prior knowledge in lessons learned in authentic inquiry. In this instance, it was the bee sting and seeing the bee’s stinger. Teacher E was a part of this process and observed as the students interpreted through observation and discourse what they were seeing. The ‘aha moment’ was an unanticipated part of the metacognitive process, according to Herrenkohl and Guerra (1998) and other workers.

Remarks group E-vii-P4 7 of 8. Teacher E stated that in using the digital microscope, the students were able to see “[the image] – all of a sudden [it] looks [like something seen before] … it makes sense to them – [at least] some of it.” The researcher noted that the teacher said that the image ‘all of a sudden … it made sense to them,’ which was a unique observation by the teacher. By looking at an object the students saw something that the students might have seen many times before but now see it again but in a different way. The researcher noted that the teacher witnessed a moment of discovery, which might have been captured on the monitor by a photograph. Perhaps, in the above instance of a stinger, an image or video of the discovery was captured, which was made possible by the digital microscope. But there was more than just the stinger**,** which was involved. This moment of discovery by the student, when observed by the teacher, was 'all of a sudden', and the words 'it looks' and 'it makes sense to them,' were words that the teacher used. However, by seeing something that had been seen before but in a different way and, in this case, magnified, the students were able to make a connection to something that happened to them in a prior experience. This was a return to prior knowledge. The researcher noted that, in the view of the teacher, this appeared instantaneously or 'all of a sudden.' It was the 'aha moment' when the 'light bulb' went on and when the connection was made. The student was then able to see an object in a different way. The change here was in the teacher's awareness of the moment of discovery by a student, which was noticed by observing what students said and did. The researcher believed that this was an important discovery.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about students making connections 'all of a sudden,' which is sometimes called the 'aha moment.' Roth (2003) emphasized that the learning community, including students working at the same time on the same thing and inquiry tools, provided the setting for students to make connections and gained insights into the things they are studying. Costa (2001) wrote about the 'aha moment' saying that individuals would reflect on what they had seen and the processes by which they saw those things and in the process make connections to other information. The ‘aha moment’ might have been part of metacognition (Donovan et al., 1998; Herrenkohl & Guerra, 1998; Pearce, 1999; White & Frederikson, 1999). Teacher E described this effect in the inquiry lessons using digital microscopy.

Remarks group E-vii-P4 8 of 8. Teacher E found that in using the digital microscope, the students were able to “see the individual pieces as you magnify it.” The researcher noted that the teacher was informed by the students that as something was magnified the students could see the individual components. The researcher noted that the language used here was not scientific but the students used language that they were familiar with to relate something that they saw (in this instance, it was ‘individual pieces.’ The change here was in the teacher’s observation of the words students used to describe what they saw while using the digital microscope.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about students using the language that they presently understood to explain scientific concepts. Roth and Lawless (2002) wrote about the evolution of discourse in the inquiry classroom. They noted an evolution of gestures into what they called muddled talk, which was simple language that communicated sophisticated ideas. Roth (2001a) discussed how language evolves in the inquiry classroom, saying that what he called scientific talk must emerge over time. He noted that descriptive scientific language emerged from this discourse.

Post-interview 2006

Remarks group E-vii-P6 1 of 2. Teacher E stated that in using the digital microscope, the students were "able to understand now that there is so much more when you are looking at anything no matter what, you see very little of what is really there …. I guess that I never thought about it before." Teacher E also noted that in using the digital microscope, the students were "able … to look differently … noticing how different things look and really being able to see a difference or change … just looking at an object … and then when you are getting closer, the things that you miss or the things that you cannot see just looking at it and even like using maybe a magnifying glass or something … but when you get up really close to something, all the things that you miss." The researcher noted that the teacher was saying how much students learned about *seeing* while using the digital microscope and how things look *so differently* under the digital microscope in comparison to the magnifying glass. The change here was in the observations of the teacher, who was informed by the students that by using the digital microscope there was more to see when something was magnified. In addition, the students looked differently at things now and that by looking at something really closely they could see things that they might have missed if it were not magnified.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about the many ways that students see differently using digital microscopy and the similar ways that the teacher sees differently too. In much the same way that Krajcik et al. (1998) viewed changes in students who participated in developing their own inquiry activities, Bell et al. (2003) noted changes in teachers and their perceptions. Crowther (1997) noted that a partnership of teacher and students worked well in inquiry activities.

Teacher E described activities where this partnership affected both the teacher and the students.

Remarks group E-vii-P6 2 of 2. Teacher E found that in using the digital microscope, the students were able to “see on currency] the watermark, you do not see it on the front, you do not see it on the back, if you are looking at it, but if you lay it on the microscope and turn the bottom light on, it shows that face of the president … it is a little ghost face … but it is like, ‘why do they do all this?’” The researcher noted that the teacher recognized how the students were experimenting with the digital microscope and what it showed them. The researcher noted the detail that the teacher used to describe what was being observed when using the digital microscope to look at the watermark on currency. Also, the teacher mentioned how the bottom light was used to ‘see’ and what it did. The teacher was specific in the description of what the students did to ‘see’ the watermark. The teacher remarked, ‘why do they do all this?’ and this showed that the lesson using currency involved inquiry-type questions, which went beyond the initial investigation and connected to the reasons that currency had these features. The change here was that the teacher became more descriptive about what the students were looking at as well as what they found. The teacher also had become more knowledgeable than before about the components of the digital microscope.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about the detail with which students investigated things like currency and asked ‘why do they do this?’ Students’ level of interest (Krajcik et al., 1998) and students’ sense of ownership (Barab & Hay, 2001) were two reasons pointed out in which students liked to be involved in their inquiry activities. Teacher E's observations about the detail with which students wanted to do their work supported this.

Interview after first lesson 2004

Remarks group E-vii-A4 1 of 6. Teacher E stated that in using the digital microscope the students were able to "magnify objects – to see the parts – but then manipulate it." The researcher noted that the students informed the teacher that when they viewed a magnified object they manipulated it. The change here was that the teacher observed how students manipulate objects as they magnified them using the digital microscope.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about student interest in magnifying and manipulating objects using digital microscopy. Jones et al. (2003) reported that students engaged in what they called haptic perception of objects, which involved touching and manipulating objects during microscopic study. Teacher E observed that the students did something similar in this instance.

Remarks group E-vii-A4 2 of 6. Teacher E stated that in using the digital microscope, the students were able "to look at anything … inside [the classroom] … [or from the outdoors] ... [saying] 'that is kind of neat,' [and asking] 'but what about this?'" The teacher also noted that the students would "get something magnified and they would not recognize it." The researcher noted that the teacher was informed by what the students said 'what about this?' The students were able to look at things inside the classroom and from the outdoors. The students were able to bring in something that they were curious about. The researcher noted that the students were interested in things that they selected to see under the digital microscope. The change here was the extent of the classroom setting which now goes beyond the walls of the classroom to the outside. This in turn changed the type of lessons that could be used with the digital microscope.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about students looking at things from inside and outside the classroom and seeing something unexpected with magnification. Seeing something unexpected was a discrepant event for the students. As noted previously, Krajcik et al. (1998) found that young children could be very helpful in providing materials for those investigations, especially when the students were highly interested in the inquiry. Also, Barab and Hay (2001) noted that students had a sense of ownership of discoveries based on inquiry lessons and that their participation, for example bringing materials from outside, increases this sense of ownership. As noted previously, Liem (1987) and Appleton (1996) discussed the aspects of learning from discrepant events, such as the students' surprise about magnification. The discrepant events in this instance emerged unexpectedly from the lesson and students used the social interaction of the inquiry classroom to resolve their cognitive conflicts.

Remarks group E-vii-A4 3 of 6. Teacher E found that in using the digital microscope, the students were able to "see a lot of things that I was not aware." The researcher noted that the students brought more to the lesson than the teacher anticipated. The students explored and the lesson went in the direction where the student interest was focused. In this instance, the students informed the teacher of what interested them by what they selected to see. The change here was in what the teacher learned about what interested the students and what they wanted to see.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about students studying what interested them and that the students saw things that the teacher was not aware of or was not expecting to see. As noted previously, Krajcik et al. (1998) found that young children could be very helpful in providing materials for those investigations, especially when the students were highly interested in the inquiry. Bell et al. (2003) noted changes in teachers and their perceptions when the teacher conducted inquiry along with students. Richardson (1990; 1991) explained teacher change in terms of the teacher's background and receptivity to change. Teacher E's perspective on magnified objects changed as a result of the digital microscope activities and what students were interested in seeing.

Remarks group E-vii-A4 4 of 6. Teacher E found that in using the digital microscope, the students were able to "see an image on the screen, but it [sometimes] was so distorted." The researcher noted that when the students observed an object on the monitor the image was distorted sometimes. In this instance, each student should realize that the object was not in focus. Therefore, to see it more clearly, the student needed to change the focus until the image was in a clearer view, but it was up to each student to do this. The researcher noted that there was some uncertainty about focusing, which the teacher discovered. The students had to adjust the focus independently so the image would not be distorted. In related comments, Teacher E discovered that in using the digital microscope, the students were able "to come closer into the object" and that in using the digital microscope, the students were able "to make it bigger." The researcher noted that the students were able to make it bigger and did not say 'magnified' yet in the discourse between teacher and students. The researcher noted that the teacher was informed by what the students were seeing or interested in that was on the monitor and also by what the students did to focus it. Even by not being in focus it also informed the teacher that the student was not quite getting it. The change here was in the language that the teacher used to describe what the students did when they observed an object in this case ‘to come close’ and ‘to make it bigger.’

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about what students said and what they saw during lessons. The teacher’s descriptions gave a picture of the teacher’s view of students’ perceptions, the language that they used to express their perceptions, and their concern over discrepant observations about focusing. As noted previously, Roth (2001a; 2003) wrote about stable language development and the students’ use of simple language and gestures in the processes of learning during inquiry. Teacher E gave examples in this part of the interview that illustrate this effect. As noted previously, Liem (1987) and Appleton (1996) wrote about discrepant events and advocated inquiry-based lessons built on discrepant events. The discrepant events in this instance emerged unexpectedly from the lesson. Teacher E noted how the students were faced with a dilemma (in effect, a cognitive conflict) about focusing and how the students used class discussion (in effect, discourse and other social interactions) to resolve their questions about what was happening.

Remarks group E-vii-A4 5 of 6. Teacher E stated that in using the digital microscope, the students “looked closely enough [to see the words on a coin that they did not know what it said].” The researcher noted that the students used the digital microscope to help find something that they were interested in and, in this instance, they wanted to see what the words were on the coin. The researcher noted that the use of the digital microscope to discover or answer a question connected to the interest and curiosity of the students. It also connected to using technology to solve a problem. The change here was in the use of the digital microscope to look for something in this case, words on a coin.

In addition, Teacher E found that in using the digital microscope, the students were able to "find things that do not necessarily come across [as] what you thought they would look like." The researcher notes that using the digital microscope there was a surprise factor that resulted from finding something that looked differently than what was anticipated. The teacher was informed by the reactions of the student to what they found in comparison to what they thought they would see. The change here was in what the teacher learned about students and the surprise they experienced in what they found using the digital microscope.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about students looking closely enough at an object in order to answer a question that came from their own curiosity and the surprise factor in discovery. That students should form questions that drive their own inquiry, was one of the suggestions given in the text *How People Learn* (Donovan et al., 1998). As noted previously, Krajcik et al. (1998) reported that young children engage successfully in inquiries where they help form the questions and drive the activity. Teacher E noted that the enrichment students had no problems forming questions that they wanted answered about coins and other things. Regarding the surprise factor, Libarkin et al. (2003) found that some young children have naïve mental models and conceptual frameworks. These students may be surprised when they encounter or experience something new (Crowther, 1997). However, the discovery that perception is wrong was an important learning experience (Donovan et al., 1998). In this instance, Teacher E described this effect as surprise among the students.

Remarks group E-vii-A4 6 of 6. Teacher E stated that in using the digital microscope, the students were “able to look at [things differently]” and “look at [things] from different levels of ... [magnification].” The researcher noted that the students were able to observe objects at different levels of magnification. The students learned to use different levels of magnification to look at objects. Teacher E also discovered that in using the digital microscope, the students were “able to see it, and ... to touch it ... put their hands on it, and do it over and over and over again.” The researcher noted that the students informed the teacher by what they did and said about an object. The digital microscope made it possible for the students to ‘be able to see,’ and they were able ‘to touch it’ and ‘put their hands on it,’ and ‘do it over and over and over again.’ The teacher learned what the students did to be able to see an object using the digital microscope. The teacher made a point of repeating this because this was something the teacher observed about what the students did when they were trying to see the object and what was revealed under greater magnification. The change here was in what the teacher discovered about what students did when they looked at something under magnification.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about the importance of the sense of touch in the discovery process and the importance of being a participant observer. As noted previously, Jones et al. (2003) reported that students engaged in what they referred to as haptic perception of objects, which involved touching objects during microscopic study. Teacher E observed that the students did something similar in this instance and that this was important to the students’ inquiry. Teacher E also participated in the lesson by giving directions and engaging in inquiry alongside the students. This method of teaching has been advocated by many educational researchers including Lansdown et al. (1971) who noted that it is a function of the personality of the teacher but is nevertheless an effective method of classroom inquiry.

Interview after lessons 2006

Remarks group E-vii-A6 1 of 2. Teacher E stated that in using the digital microscope, the students were "able to give a whole different look … you would think, 'gosh, that is different.'" The researcher noted that the students obtained a 'whole different look' from something that they observed. This implied that there was a variety of things that were observed and that what was observed was dependent on the individual student. Teacher E also noted that in using the digital microscope, the students were able to "get up close to objects … seeing [them] in a different way." The researcher noted that in order for students to 'see in a different way,' there was a connection to the students' getting close to objects. The change here was in the teacher's knowledge of what interested the students and what they were able to 'see.'

In addition, Teacher E found that in using the digital microscope, the students were able to "see a lot of objects that you would not imagine that that is what it is going to look like … you know, ten times the magnification, you might say of course that is what it looks like, but when you get the multiples higher … ." The teacher noted that it was more difficult to imagine what will be seen under higher magnification. The teacher was informed by what the students did and that they were able to imagine the object when it was under low magnification but they did not expect what it looked like under higher magnification. The change here was in the observation of the teacher that when students magnify an object it might be difficult to predict what it would look like under magnification.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about individual student's perceptions of objects seen using digital microscopy and seeing in a different way. Libarkin (2001) reported that young students had many partially correct perceptions that carry over into how they see the world. Kusnick (2002) referred to conceptual prisms in this regard. These perceptions affected some students' abilities to make sense of what they were seeing in an inquiry setting (Chi et al., 1994). Teacher E noticed student perceptions such as these during the inquiry lessons.

Remarks group E-vii-A6 2 of 2. Teacher E discovered that in using the digital microscope, the students were able to "quickly learn little tidbits about … if you are at 10 X [ten times] and you move an object, you would still see it, but if you at 200 X [two hundred times], and you bump or tap it … it would come completely off the screen." The researcher noted that the students informed the teacher by what they learned when there was a slight bump or tap at low magnification versus the same tap under higher magnification. The researcher noted that the students 'learned quickly little tidbits' by experiencing it for themselves. The researcher noted that the teacher mentioned 'learning quickly' and related this to something that happened to the students, which required the students to try something else or 'make sure you don't get bumped.' The actual act of 'bumping' and causing the image to go off the screen required a time for the students to be able to fix what had happened. The researcher noted that the students informed the teacher that they learned how to be able to focus at higher magnification by comparing ‘why it did not happen like that’ at lower magnification and in the comparison realized that a slight bump or tap or movement would not affect the lower magnified image so much but would greatly affect a higher magnified image. There was an event that was compared to another event that caused questioning. In the act of finding the answer to the question, the students gained a leap in understanding, in this instance, understanding why a slight bump matters more at a higher magnification than a lower magnification. The change here was that the investigation using the digital microscope provided a springboard for students to understand a complex idea of magnification because of something they experienced. In this instance, it was a bump and that affected the seeing of the object. In turn, this bump was not as noticeable under lower magnification. This in turn led the students to inquire why this was different under higher magnification. In the comparison, the students were able to connect low to high magnification with the results of movement.

In teacher remarks about *seeing* with regard to the digital microscope, Teacher E spoke about how students learned from the situation when the digital microscope was bumped and it was either on low or high power. As noted previously, Jones et al. (2003) referred to haptic perception with regard to students’ learning about electronic microscopy. This haptic perception could include more than touching the objects. In this case, it involved handling the microscope as well.

Category – Students

Pre-interview 2004

About the digital microscope and *students*, specifically how it would help them, Teacher E anticipated that the digital microscope would “help children who have bad eye-sight” and would “help a student who has no experience” in using a microscope. The teacher felt that the digital microscope would “add excitement with the children.” And, the teacher predicted that the new digital microscope would make students “feel that something [interesting] is coming.” Also, the teacher added that the digital microscope “would spark them [the students]” and that they “would feel empowered.” The teacher stated that in using the digital microscope, the students “would feel scientific” and that the students “would make some choices or decisions with the availability if we are in the computer lab.”

About the digital microscope and *students*, specifically what would happen during inquiry, Teacher E predicted that the students “would guide it,” “would maneuver it on their own,” “would handle it,” and “would touch it.” The teacher anticipated that in using the digital microscope, the students “would do self-exploration without any help.” The teacher felt that the students “would be interested in seeing how … that works and why does that work.” Also, the teacher expected that in using the video functions, the students “would be the next director or cinematographer.” The teacher expressed that the students “would get every bug in the back yard and stick it under there.” And, the teacher anticipated that the students “would [also] have it at home.” The teacher went on to say that the students “would look at [various things that] spark their interest.” The teacher expected that the students “would see it as play (and so) they will do it.” The teacher expected that the students “would [discover] something happened that you did not expect.” Further, the teacher expected that in using the digital microscope, the students “would enjoy experimenting.” And, the teacher anticipated that in using the digital microscope, the students “would start asking questions.” In connection with this, the teacher added that the digital microscope “would churn them up a little.”

About the digital microscope and *students*, specifically how it would make the students feel, Teacher E anticipated that in using the digital microscope, the students “would gain a lot of confidence.” And, the teacher expected that the students “would feel pretty comfortable about how scientists learn.” The teacher expressed that the digital microscope “would get them [students] using something that they have not used before” and “would get them more interested in science area given them.” The teacher predicted that in using the digital microscope, it “would be helpful … [to] students” and “would interest them [the students] in nature.” The teacher noted that the students “would find out how scientists work” and that the digital microscope “would give them the idea that this is what real scientists do.” The teacher stated that the students “would understand how scientists learn.”

Researcher summary (students) from pre-interview. In teacher remarks coded in the category *students*, Teacher E expected that the students would see and do using the digital microscope. Regarding how digital microscopy would help students, the teacher spoke about helping students see, understand microscopy, and sparking their interest in science. Regarding how digital microscopy would affect inquiry, the teacher mentioned handling the digital microscope, student self-exploration, studying how and why things work, using the video functions, collecting bugs to study, following their interests, seeing the lesson as play, experimenting, and students asking questions. Regarding how digital microscopy would make students feel, the teacher anticipated that the students would gain confidence, feel comfortable about how scientists learn, become interested in science and nature, and would help students understand how scientists learn and what they do.

Post-interview 2004

Remarks group E-viii-P4 1 of 4. Teacher E stated that the digital microscope "just made it easier because sometimes you get some kids who just have no ability to focus in on something or to notice things but when the kid beside him sees it and says 'oh, look at this' – they could share it real easily." The researcher noted that this was a very important observation made by the teacher after observing students working together. Some students may have difficulty focusing in on something or to notice things on their own, but by working with another student, they could see it ('oh, look at this.') In this way, the two students could share the digital microscope and their discoveries. The researcher noted that what the students did and said informed the teacher that working together helped the students share the experience of seeing. The change here was that by having students work together using the digital microscope it led to a better understanding through the discourse between students.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about what students said and did, which described student discourse during the learning process in a classroom community. Roth (1994; 1999) wrote about the importance of student discourse in a classroom community. He noted that it was important for students to engage in discourse, including gestures and body language, as the learning community grapples with new discoveries and comes to new understandings. Roth (1996b) noted that an actor network tended to develop in classroom communities and that some principle actors made breakthroughs, which Roth called tracers, that propagated through the community. Teacher E saw something similar occur within pairs of students, but it was likely that this occurred across the classroom.

Remarks group E-viii-P4 2 of 4. Teacher E found that in using the digital microscope, the students "get into the insects because that was something that [the students] were all interested in." The researcher noted that the teacher stated that the all students were interested in insects. Also, Teacher E remarked that the digital microscope was "very child friendly, very easy to use." This statement affirmed comments of the same type made previously by the teacher. In addition, Teacher E noted that in using the digital microscope, the microscope itself "helped get [the students'] attention." Also, Teacher E found that in using the digital microscope, the microscope itself was a way to "get everybody to participate." The change noted here was that the digital microscope helped everyone to participate and kept the students' attention, which was not the case with lessons using the light microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about what students were interested in and also the digital microscope and its ability to get students' attention and encourage all students to participate. Roth and McGinn (1998) described learning environments where students could conduct investigations in an authentic way, which they said encouraged student discourse during the lesson. A part of the authentic concept is student-driven inquiry and the pursuit of what students are interested in. Roth (1996b) described the transformation of an inquiry-based classroom when a new tool was introduced and used by all students. He noted that the tool's introduction transformed the setting in the classroom. Teacher E remarked on the attention and participation seen in digital microscopy lessons, which was similar to Roth's observations.

Remarks group E-viii-P4 3 of 4. Teacher E stated that in using the digital microscope, the students "look at it [as] more of a fun nature-type activity than a laboratory experiment." The researcher noted that the teacher was informed by the students that using the digital microscope was different from what they expected. The change noted here was that the students had more fun and felt as if they were doing a nature activity rather than laboratory work using the standard light microscope. From this could be inferred that the students prefer this kind of learning situation instead of a regular 'laboratory experiment' (in other words, the standard light microscope).

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the way that the students responded, which revealed the role of fun and enjoyment in student interest and enthusiasm in digital microscopy. Donovan et al. (1998) noted the importance of engaging young students in inquiry and the necessary role of play in this process. And, play was part of the recipe for success in the classroom (Crowther, 1997). Teacher E remarked on this in referring to 'fun and enjoyment' among enrichment students doing inquiry.

Remarks group E-viii-P4 4 of 4. Teacher E found that in using the digital microscope, the students "see science differently." The researcher noted that the teacher was informed by the students that the digital microscope gave the students a different view in which they could see science differently. The change here was in the way students view science. In addition, Teacher E noted that in using the digital microscope, the students "see how excited they could get about it [microscopy]." Also, Teacher E noted that in using the digital microscope, the students were “being inquisitive about it.” The researcher noted that the change here was that the students were excited and inquisitive about using the digital microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students seeing science ‘differently’ after using the digital microscope and students getting excited and being inquisitive about using digital microscopy. Roth (1999) described the phenomenological understanding gained by students who used new inquiry tools in a classroom community. This phenomenological understanding permitted students to more readily adapt to new experiences using the inquiry tools. Teacher E noted something similar, which the teacher expressed as ‘seeing differently.’ In addition, Donovan et al. (1998) noted the importance of engaging young students in inquiry using student energy and excitement about learning. Liem (1987) stated that excitement was essential to the inquiry classroom and that teacher’s excitement is important during the lesson. Teacher E remarked on this in referring to ‘getting excited’ and ‘being inquisitive’ during lessons.

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Remarks group E-viii-P6 1 of 27. Teacher E found that in using the digital microscope, when the students were “looking at it up close [it] does not look like what they [were originally] looking at.” The researcher noted that the teacher was informed by what the students said about looking at an object up close. The researcher noted that the students were investigating what the object looked like without magnification and then when the object is magnified. This comparison between the object and the magnified object caused a discrepancy in the minds of the students and they were questioning the magnified image. The change noted here was that the teacher was informed by the students that what they were looking at did not look like the object. This was similar to discrepant events, which cause questioning and inquiry into why something happened.

In a teacher remark about *students* with regard to the digital microscope, Teacher E spoke about students noticing that objects under magnification did not look much like the object itself. Jones et al. (2003) noted that students commonly have a different perception of what an object would look like under magnification and those students tended to arrive at a better understanding of what they were seeing as a result of social interaction during microscopy studies. Discrepant observations about magnified objects led to social discourse, which in turn led to learning (Appleton, 1996). The discrepancy brought up cognitive conflict among the students, who then learned from resolving the experience (Liem, 1987). Teacher E discovered this effect as students grappled with what they were seeing using the digital microscope.

Remarks group E-viii-P6 2 of 27. Teacher E found that in using the digital microscope, the students "enjoy looking at things." The researcher noted that the teacher remarked about how the students enjoyed looking at things using the digital microscope. The teacher anticipated that the students would enjoy doing this. Teacher E stated that in using the digital microscope, the students responded to "the digital blues [a name the teacher gave to the digital microscope] – if I ever have them out – the kids are like little magnets to it." The researcher noted that whenever the teacher had the digital microscope out the students were naturally drawn to them. The change here was that the teacher was informed by the students' attraction to the digital microscope. Teacher E found that in using the digital microscope, the students learned about digital microscopy and had became familiar with it saying “I think in the beginning they really did not understand much about it and now that they have become more familiar with it, they are quickly drawn to it.” The researcher noted that the teacher observed that the more familiar the students were with the digital microscope the more quickly drawn in they were. The researcher noted that familiarity accompanied attraction to the digital microscope. The change here was in student understanding; the students went from not understanding in the beginning to becoming more familiar with it as they were quickly drawn in.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the students’ actions and comments, which revealed how the students’ curiosity was driving the inquiry lesson. As noted previously, Donovan et al. (1998) and other authors have noted the importance of engaging young students in inquiry using student curiosity and excitement about learning. Teacher E remarked on this in referring to being drawn to the digital microscopes ‘like magnets’ and how quickly the students embraced using this microscope technology in their lessons. This followed closely the observations of Liem (1987), who wrote that enthusiasm was contagious and urged teacher to convey this excitement to students as Teacher E was doing here.

Remarks group E-viii-P6 3 of 27. Teacher E stated that in using the digital microscope, the students “like to look at them.” The researcher noted that the teacher observed that the students liked the appearance of the digital microscope and that the appearance of the digital microscope was important in its appeal to the students. The change noted here was that the digital microscope’s design was different from the standard light microscope and that the students were more attracted to the digital microscope’s appearance. In addition, Teacher E noted that in using the digital microscope, the students at first might have thought that it would “be like using a hand lens, [and] they like that … [however, in using the digital microscope] they like the ability to change and maneuver and to see and to look around and it is not limited.” The researcher noted that this was an important observation by the teacher – comparing how the students liked using the hand lens and what the hand lens did. However, about the digital microscope, the students informed the teacher by what they did and said that ‘they like the ability to change, maneuver, to see, to look around, and it is not limited.’ The researcher noted that the students informed the teacher by what they said in comparison to a hand lens, and this informed the teacher of what students did when they liked something using the hand lens but they also liked the ability to change, the ability to maneuver, the ability to see and look, and the ability to look around and the ability to not be limited. The change noted here was that the teacher was able to transfer what students liked about the hand-lens and connect it to the digital microscope which could be used in similar ways.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the students’ actions and comments, which revealed their feelings and level of interest. The students were excited and their interest level was driving the lessons, which had become open-ended, self-discovery lessons using digital microscopy. As noted previously, Donovan et al. (1998), Jones et al., (2000), and other authors noted how readily young children engage in inquiry-based activities, especially those involving innovative tools. Roth and McGinn (1998) observed this enthusiastic response and noted that young children, like scientists, naturally engaged in problem-posing, problem-solving, and persuading peers. Open-ended, or divergent, questions in inquiry lessons have been used for some time (Carin & Sund, 1970) and were particularly effective because a variety of responses and correct answers further stimulated discussion. Teacher E observed similar things among the enrichment students whose enthusiasm and curiosity were driving the lesson.

Remarks group E-viii-P6 4 of 27. Teacher E stated that in using the digital microscope, the students "can look at a million things between when you start your directions until [you] are done … they like that ability … the difference in [digital microscopy]." About the hand lens, the teacher added "it just does not get as close up … the kids will say 'I can see it okay,' but 'I can't see it great' … [for example when] we were looking at money with mintmarks." The teacher added "the hand lenses were fine … they could see what the letter was … but then when you do that same thing with the [digital] microscope, you not only see that but you see the actual [features] – any indentation, any marks, any anything … a kid might [misidentify] something that they see using the hand lens, but you are not going to make [that] mistake using the [digital] microscope … it is so much clearer." The researcher noted that the teacher was making a comparison to the hand lens and the teacher was informed by what the students did and said. The teacher described what the students did when they like looking at things with the hand lens. The researcher noted that the teacher remarked that the students liked to look at a million things, and they liked that ability. The researcher noted that the teacher stated that the hand lens did not 'get as close up' as the digital microscope. The teacher gave an example of looking at coins with mintmarks with the hand lens where the students could see what the letter was and then compared it to looking at it with the digital microscope. The teacher became very descriptive in the detail of the lesson as it was recalled. The teacher mentioned that to see using the digital microscope the students could see any indentations, any marks. Then the teacher mentioned that the students could mistake something they were seeing with the hand lens but this was not the case with the digital microscope. The researcher noted that this observation by the teacher was important because the teacher was informed by what the students said as well as what they did. These observations allowed the teacher to be informed to what the students are seeing with the hand lens versus the digital microscope. This comparison was an important part of the lesson where the students could use the prior experience with the hand lens and then could relate what they were now seeing with the digital microscope. This informed the teacher not only what they were seeing but what they had not seen previously. The students liked to look at a lot of things and the hand lens allowed the students to investigate many things, but the limiting factor was that although they could see a lot of things they could not see them that well. The digital microscope in the hand-held mode was a lot like the magnifying lens because the students had the freedom to look at a variety of things that would not be able to be seen using the stand and regular microscope. The change here was that the teacher was very informative about what students wanted and liked and made the comparison between the hand-lens and the digital microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about comparisons between the hand lens and the digital microscope and indirectly the importance of student discourse during inquiry. Roth (1996b) noted the transformation of an inquiry lesson by the introduction of a new inquiry tool. As the new inquiry tool was introduced, there was discussion of how it compared to older tools that it replaced. Much of this discussion was among principle actors, but soon the discourse included peripheral participants. Teacher E's remarks covered over what students were saying and described some of the discourse over the transition to this new tool.

Remarks group E-viii-P6 5 of 27. Teacher E found that in using the digital microscope, the students would "study the one-dollar bills with one of my groups." The teacher added that "I was standing at the back of the room and I would direct them" and "I would just let the children have a bit of time exploring." The researcher noted that the teacher was standing at the back of the room and was able to direct the students because it was a computer lab and the teacher had a monitor that could be seen at the front of the room. In this way, the teacher could also see all the monitors of the students. The researcher noted that Teacher E provided time for student exploration. The change here was in the ability of the teacher to be able to observe all students and what they were viewing using the digital microscope from one place in the classroom. Also, the teacher stated that this allowed for the teacher to direct the students. The change noted here was in room arrangement and teacher-student interaction that was possible because of the technology of the digital microscope.

In addition, Teacher E expressed that in using the digital microscope, the teacher "would let the children share." The researcher noted that Teacher E provided an opportunity for student sharing. The researcher noted that the teacher would let the students share or have discourse that included the comment "oh, I found this," to which the teacher remarked "come on up and show this to the class." The researcher noted that the teacher let the students share with other students. The teacher commented that "the kids were leading the group." The researcher noted that the teacher allowed for students to lead the group. The teacher added that “they would bring their dollar and they would lay it on [the teacher’s digital microscope]” and “they would say ‘look, here is what I see.’” The researcher noted how the students brought their own currency to study and how effective that was. The teacher noted that there was a Sympodium™ connected to the big screen in the room, which also allowed all students to see what others had found. The researcher noted that using the digital microscope allowed the teacher to be able to let the students share what they had found using their own digital microscope. The teacher was informed by what the students did and said. The students’ discourse led to sharing and that led to use of the classroom Sympodium™. The teacher said “they circled on the Sympodium what they found and remarked ‘this is to show.’” The teacher added “and, then the next kid would come and find something different … and this kid would … [find something else] … then one kid was looking at the letter – like on the one-dollar bill on the left side there is a large capital letter, a circle, seal-looking thing – well, then we found out that that tells where the bill was issued from, which Federal Reserve Bank.” The teacher went on to say: “Well, then they looked around … [and found even more things like that].” The researcher noted that the students’ sharing caused other students to look, to compare, and then to see not only what the other students saw but also something else that no one had shared. This led to better understanding all around. In this example, the teacher stated that the students would say ‘look – here is what I see’ and then they ‘would show others.’ The researcher noted that the students said and showed what they could see and then they pointed out what they could see on the teacher monitor that could be seen by all the students. The students used discourse and also communicated by gestures such as pointing out things. This pointing to different things caused other students to check their own images and to compare them to what they were seeing. That led to further investigation and students' finding some things that had not yet been found by the other students. The change here was in the impact that the digital microscope and its related components had on the interest and the participation of the students in discovery.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about what students did and said during a lesson on closely examining currency. The teacher's comments illustrated student interactions during an inquiry lesson on currency, and how student discourse and gestures promoted learning in this student community. Roth (1994) stated the view that students in an inquiry classroom act much like scientists in communicating their findings and discoveries across the classroom community. Roth (1994) found this particularly effective when a representational device of some kind was in use. Roth (1994; 1999) found that discourse and gestures and body language of students was important as well in communicating findings and diffusion of knowledge in the inquiry-based classroom. Roth (2000; 2003), Roth and Welzel (2001), and Roth and Lawless (2002) reinforced this understanding of student behaviors in studies of ergotic hand movements and other symbolic expressions plus discourse in the inquiry classroom. Teacher E mentioned the many student interactions (i.e., discourse and gestures) going on during this lesson, which is particularly important because this follows very closely the *knowledge diffusion* phenomena discussed by these authors and others who have looked into student interactions in the classroom setting.

Remarks group E-viii-P6 6 of 27. In using the digital microscope, Teacher E conducted lessons on examining details on U.S. currency at different magnifications. The following are comments taken from an exercise that the teacher spoke about: “And I was standing at the back and it was like the entire room had – I want to say F is Atlanta, I do not know why that is so – but anyhow, the entire room had Fs … and there was one [bill] that was K and one that was L or I, you know it was like sporadic other letters, but say 80 percent of them all were … [Fs].” “And that got us to talk about why are they all – or most of our bills – from the Atlanta – and it says Atlanta, Georgia, under it. Why is that? And they are like, ‘we are close to there;’ does that makes sense?” “But how do we get money from, let’s say, California or Texas or from, you know? And they said, well, if a guy was going, let’s say a man was traveling and maybe he is from California but he came here on business, he would spend his money here. And I said exactly.” “So, then they were imagining how or maybe somebody from A… or somebody from our area went there and they bought something and got change back. And for them to understand that – you know – it talks about I bet most of their money over there has a K on it for their Reserve Bank.” The researcher noted that the teacher’s position in the classroom was advantageous to promote the discovery of something that could not have been seen before either using the digital microscope or other in other kinds of lessons. The teacher’s view of the students’ computer monitors led the teacher to a discovery that redirected a lesson from random details to where dollar bills come from. This, as mentioned by the teacher, was a topic that the teacher could not have planned and was learned by participating in the lesson along with the students. In this way, the direction of the lesson emerged from the lesson itself. The researcher noted that the teacher was informed not only by the students’ discourse, but also by what they were doing. Further, the teacher was informed by what the students had discovered and put up on their computer monitors, which was another form of communication, a digital communication. The teacher was also a learner and so the teacher was able to share with the students questions of ‘why is that?’ The researcher noted that the teacher used inquiry after discovery, which changed the direction of the lesson. The change noted here was the use of the digital microscope in an investigation of currency, which led to interactions between students and further inquiry with the teacher participating in the discovery process. The teacher noted: “You know, it was just the reasoning skills.” The researcher noted that the teacher noted that the students used reasoning skills, which was also a product of their interaction.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about a lesson on U.S. currency, including the students’ discussions and interactions. In these lessons, student discourse and discovery drove and redirected the lesson and digital communication played a key role. As noted above, Roth (1994) found that students in an inquiry classroom act much like scientists in communicating their findings and discoveries across the classroom community. He found this particularly effective when a representational device of some kind was in use. In this instance, the representational devices were the computer monitors connected to the digital microscope and the big screen at the front of the room. The students made discoveries that enhanced and changed the lesson. Roth (1996b) noted a similar effect when a new tool was introduced, which transformed the learning community of the inquiry classroom. Roth (1994; 1996b) found that student discourse was the driving force behind the inquiry lesson and its evolution. The teacher’s remarks illustrated the impact of student discourse and of representational devices, and how they changed the lesson. Digital communication, which played a key role here, was discussed in some detail by Davidson (1995-2004), who envisioned this type of classroom communication just after digital microscope technology emerged in the late 1990s. Parker (1995) examined student fascination with paper currency and mentioned student reactions much like those reported by Teacher E.

Remarks group E-viii-P6 7 of 27. Regarding the inquiry lesson on U.S. currency, Teacher E went on to say: “But it was weird that, first of all, I never really noticed or knew what that seal was … but, then they all got interested so then from then on out, ‘people come and tell me’ – you know ‘I had a bill that had such and such on it’ … but, their being more aware of it has brought [up many other examples].” Regarding using the big screen at the front of the room (and the related Sympodium™), the teacher remarked “because everyone’s [image] was up [on the screen] … the seal was about that big so it was like – boom – and it just said F - all the way across [almost everyone had the same image] … and it just was like – ‘wow’ … and then I saw just like one, two, three that weren’t [Fs].” The teacher added: “You know, I do not know if any of the other kids were that taken with this … but I was stepping behind them, they are looking at their computer, and I am looking across the room … but then it just led us … the conversation grew from that … so that was that, you know.” The researcher noted that the teacher had a lot of information to share with the researcher about something that happened during the lesson. The teacher described what happened, saying ‘it was weird’ that the teacher never noticed or knew what that seal on the U.S. currency represented, but then the students became quite interested. From then on, students became more aware. The teacher realized this and said ‘the seal was so big it was like – boom – and it just said ‘F’ on student monitors all the way across the room.’ The researcher noted that the teacher noted that the seal’s size on the screen caused the teacher to become aware of something that the teacher had not seen before. This led the teacher and the students into a conversation that grew from what they discovered. The researcher noted that the teacher described what happened in unusual detail and this detail seemed to propagate from the enthusiasm and the energy that the teacher experienced as a participant in discovery. The researcher noted what the teacher observed from ‘stepping behind them,’ which allowed the teacher to get a perspective and view on what was going on in the classroom. The researcher noted this was one of the most important statements made by this teacher about the influence of the digital microscope on discovery by all participants, the students and the teacher as well. The change here was multi-dimensional and it showed the change in the way the teacher became engaged in the lesson and the teacher’s ability to describe what was happening in the classroom as an observer and as a participant.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about what students did and said during a lesson on U.S. currency. In this lesson, teacher and student discourse, and their discovery drove the lesson. As noted above, Roth (1994) found that students act much like scientists in communicating their findings and discoveries across the classroom community. The teacher and students had a partnership in this kind of classroom (Crowther, 1997; MacKenzie, 2001), which encouraged both teacher and students. This lesson involved both teacher and student discourse and discovery, which was an unexpected outcome of the lesson.

Remarks group E-viii-P6 8 of 27. Teacher E stated that in using the digital microscope, the students showed an interest in videos and the teacher commented "all want to make movies … but, they will make movies of a still object … I am [saying to them] you have got to have movement for a movie … and that was a revelation to them." The teacher added that "they were like, 'oh, yeah' … they would take the coins and move them around or the [plant's] leaves or the – you know [and] they would find movement … they like to watch [movement]." The researcher noted that the teacher made the statement that all the students wanted to make movies and they tended to want to make movies of still objects. The teacher was informed by what the students did and said and found by observation that students would 'take the coins and move them around' because 'they like to watch movement.' The teacher informed the students that 'you have to have movement for a movie.' The researcher noted that the teacher was informed by what the students did and said in statements like 'oh yeah' and the observation that the students 'like to watch' the video that they made. The teacher found that the students like to move the objects around and they thought this was 'making a movie,' which it was but not in the same way as the teacher was thinking. The change here was in the instructions about making a movie and the teacher finding out that these instructions had other interpretations by the students.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students liking movement and wanting to make videos of movement even though the movement was not part of the object's nature. Chi et al. (1994) noted that young children may have misperceptions about objects, including mistaking living and non-living characteristics and the difference between growth and stasis. In this context, it was not difficult to imagine that students might not see that the teacher's desire to have them look at something moving (as with an insect or a growing crystal) was different from adding movement to a static object by touching and pushing it under the digital microscope.

Remarks group E-viii-P6 9 of 27. Teacher E found that in using the digital microscope, the students showed a preference "to be able to have their own [microscope and things to look at]." The change here was that the teacher learned that the students preferred to look at things that they were interested as well as use their own microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students preferring to have their own digital microscope. Roth (1996a) found that some students in an inquiry classroom were principle actors and tended to lead the inquiry as others more peripheral followed along. Teacher E's comments were likely related to principle actors who were more vocal about their preferences. Roth (1996b) also discussed the effect of new tools and noted that after principle actors use new tools, other students gained a similar desire to use the tool.

Remarks group E-viii-P6 10 of 27. Teacher E stated that in using the digital microscope, the students enjoyed viewing "growing plants [and] … they could bring their plant in with them and we could … take the pictures and then they could go back and use that [in other lessons]." The researcher noted that the teacher remarked that the students could observe plants that they might be growing as part of another lesson or class activity and could make pictures of those growing plants. The change here was that the teacher could have a lesson on growing plants that utilized the digital microscope and its ability to take photos and that was an on-going lesson which could take place while the students were doing other lessons.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students using the digital microscope to observe changes in plant growth over time. Chi et al. (1994) noted that young students' learning was enhanced when they work with ontologically compatible concepts. In this instance, the compatible concepts were plant growth and change over time, as viewed in digital microscopy. Teacher E's lesson showed that the teacher used this opportunity to merge these concepts with digital microscopy in an on-going lesson.

Remarks group E-viii-P6 11 of 27. Teacher E noted that in using the digital microscope, the students could "get close enough to see [things that you might not expect, for example, a student might think] 'my hands do not look dirty.'" The teacher added "and you talk about 'wash your hands before you eat' and they [might] put it on their hands [under the digital microscope and] say 'ooh, I do need to wash my hands' … or, they would [look at] something like a mark on their hand … and it did not look like a very big mark, it might be an ink mark or something [but it would show up under the digital microscope]." The researcher noted that the teacher used the digital microscope to inform the students of a potentially good reason to wash their hands. It was a practical lesson, and it was also an experience to which the students could relate. The change here was including a part of the health curriculum involving personal hygiene and well-being.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about using the digital microscope to help understand the underlying reason for washing hands. As noted above, Chi et al. (1994) discussed how young children's learning was enhanced when they work with ontologically compatible concepts. In this instance, the compatible concepts were cleanliness and washing hands, as viewed in digital microscopy. Teacher E used this opportunity to merge these health-related concepts with digital microscopy in an on-going lesson.

Remarks group E-viii-P6 12 of 27. Teacher E stated that in using the digital microscope, the students “like to look at anything.” The researcher noted that the teacher was informed by what the students did and said that they liked to look at anything using the digital microscope. For example, the teacher commented that the students “like to look at things and say ‘ooh, it is dirty’ [or] to describe something they saw under the digital microscope or the students look at [something] and [say] it was like ‘oh, look at that it is huge.’” The teacher added that “it was just amazing to watch them look at things.” The researcher noted that by observing the students the teacher remarked that it was ‘just amazing’ what the students did and said as they looked at things. The change here was in the teacher’s interest level and being amazed and interested in what the students said and did when they used the digital microscope and the things that they found interesting. The teacher was informed about student feelings and interests by what they said about different objects. For example, phrases such as ‘ooh, it is dirty’ or ‘oh, look at that it is huge,’ informed the teacher of their feelings and interest.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about some of the comments that students made that informed the teacher of their interest level. In studying the perceptions of young children, Nakhleh and Samarapungavan (1999) noted that students had preconceptions or beliefs about matter that form frameworks that were expanded by their experiences with microscopy. Jones et al. (2003) found that young children's perceptions were quickly changed after using electronic microscopes. In the present situation, Teacher E noted that students rapidly changed perceptions as they saw familiar objects under magnification.

Remarks group E-viii-P6 13 of 27. Teacher E found that in using the digital microscope, the students "look at something and [if] it looked like a design [on the one-dollar bill] … they would put the [digital] microscope on it and it would say five or it would say ten or twenty, and they take it off and look at it [with their eyes] and they would put it back and they would look at it [again]." The researcher noted that the teacher was observant of what the students did when they were looking at a design on the one-dollar bill. The researcher noted a sequence of events when the students looked at something using the digital microscope: they looked at first, then put it under the digital microscope, saw some numbers, took it out, looked at it again with their eyes, and then put it back under the digital microscope for another look. The researcher noted that the teacher was informed by this sequence of events that the students did in order to observe something that interested them. The change here was in what the teacher learned about the things that the students were interested in while looking at U.S. currency. The teacher also became more observant in finding out what students did to look at the currency. The students found a design, put it under the microscope, took it off, looked at it, put it back, and looked again. The teacher noted that the students repeated the act of looking a number of times and that they were not satisfied with just looking at something only once, which was an important observation and informed the teacher that the students needed to look at objects more than one time when they were interested in something.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students' repetitious observation of objects that they were seeing for the first time. As noted above, in studying the perceptions of young children, Nakhleh and Samarapungavan (1999) noted that students had beliefs about matter that were expanded by their experiences with microscopy. Roth et al. (1999) noted that students used specific gestures, among them repetitive movements, during community learning situations as they gained confidence about what they were seeing. In the present situation, Teacher E noted that students checked and rechecked their observations as they were undergoing change in perception about what common objects look like when viewed close up.

Remarks group E-viii-P6 14 of 27. Teacher E found that in using the digital microscope, the students "love looking at their mouth, and their ears, and their head, and their body … the students love to look at anything." The teacher added that "they were looking at things that had skin or when it was hair, or when it was something that … they would just go 'oh my gosh, that is what that looks like' … or they would put their tongue … you know, stick their tongue out, and try to take a picture of it – and I kept saying 'now, don't lick the [microscope] … but it did not matter." The researcher noted that the teacher was informed by what the students did or said such as 'oh, my gosh – that is what that looks like' which informed the teacher that the students have made a discovery. They also took a picture of their tongue – something that they normally could not see up close. By taking a picture, the students could see it on the monitor so the digital microscope made looking at their tongue closely possible by using the picture function of the digital microscope. The change here was in using the digital microscope to explore things that could not have been explored using the standard light microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the amazement and excitement of students seeing objects up close for the first time. As noted above, in studying the perceptions of young children, Nakhleh and Samarapungavan (1999) noted that students had beliefs about matter that were changed by their experiences with microscopy. Liem (1987) found that young children's excitement was so important in inquiry lessons that it was essential to learning and could turn a child's thoughts to new career choices. In the present situation, Teacher E noted that students were especially fascinated by things that they saw all the time, but had never seen up close with such detail.

Remarks group E-viii-P6 15 of 27. Teacher E found that in using the digital microscope, the students experienced something the teacher described as "tricking the eye." The teacher noted "and the things on the coins never seemed magical [before] … you know, [they] did not seem tricky … but every [little thing deserves attention, for example] … the things that they did not notice, were like the rim on a penny … and the new pennies seemed to have a huge rim and the old pennies had not very much rim at all." The researcher noted that the teacher informed the researcher of what the student were able to see and it was something that the teacher did not expect the students to find interesting such as the rim and the wear of the coin's rim over time (found by comparing new versus old pennies). The researcher noted that the students were able to use the digital microscope to examine coins and compare them and make statements about their relative wear effects. The researcher noted that the lesson was being driven by the interest of the students uncovering unusual details about coins. Further, the students' interest drove the lesson in a direction that the teacher did not anticipate because the teacher was not aware of the interest that students had in this particular characteristic. The change here was in the accidental discovery of finding details that were not expected by the teacher or the students.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke again about the amazement and excitement of students seeing objects up close for the first time. The teacher remarks also addressed how the lesson changed to a more open-ended type of inquiry. In studying the perceptions of young children about natural objects, Shepardson (2002), Hawley (2002), and Ford (2003) noted that the children tended to think of the objects in terms of themselves. In this instance, Teacher E reported that the students responded in this way by thinking of the coins as magical or something that tricked the observer. Liem (1987) described amazement and excitement among young children and how important it was to nurture this feeling about the inquiry material. Teacher E did this in conveying excitement about studying the coins, and it aided the lesson's success. As noted previously, open-ended, or divergent, questions in inquiry lessons have been used in inquiry lessons for some time (Carin & Sund, 1970) and were especially effective because there were a variety of responses and correct answers, which further stimulate discussion. Based on the teacher's remarks, these kinds of questions affected the currency lessons.

Remarks group E-viii-P6 16 of 27. Teacher E found that in using the digital microscope, the students "liked that it was … one per person or one per group; that they were closer to [the digital microscope] than if it were [a single instrument]." The teacher added "a lot of times I said that [in] using the digital microscope the students … have [a number of] microscopes that might be four or five to a group [and it was important that] they could get their own personal time with it." The researcher noted that this was an important observation of what students wanted and needed. Teacher E remarked that the students enjoyed the 'ownership' of their own digital microscope. The students were 'closer to it' when they had their own microscope. In a way, this was another version of seeing and being closer to the object. The researcher noted that the ability of each student to be able to view an object closer could be a logistics question depending on the availability of the digital microscopes. The teacher noted that the students enjoyed their own personal time with it. The researcher noted that this was different than sharing what they experienced with each other. It perhaps was based more on how the students used their own individual computers. The change here was in the teacher learning that the students wanted more time with the microscope but also the importance of the students' proximity to the microscope and having personal time with it.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the desire of students to have their own microscope and the sense of ownership of the instrument. A sense of ownership had been identified by Barab and Hay (2001) and other researchers who pointed out that students enjoyed a sense of ownership of their discoveries. Considering that the digital microscope was the source of the findings and that the images in digital microscopy were stored on the computer connected to the digital microscope, the students might easily convey this ownership concept to the equipment as well.

Remarks group E-viii-P6 17 of 27. Teacher E stated that in using the digital microscope, the students "liked that it was easy to focus, and easy to change the settings." The teacher also found that in using the digital microscope, the students "liked that it was something that we let them handle.” The researcher noted that the teacher observed how the students enjoyed the ability to focus and change the settings on the digital microscope easily. The researcher noted that the teacher allowed the students be in charge of the digital microscope, which was different from using and sharing the standard light microscope in past lessons. In addition, Teacher E found that in using the digital microscope, the teacher “expected for the kids to enjoy it, because it is something new, something different … I did not expect [the excitement] to last as long [as it did] – and the excitement is still there … I felt like it would wear off … I just did not know how many areas I would be able to use it.” The researcher noted that this marked a change in what the teacher expected and that students would enjoy – something new and different. After time passed, the students still had the excitement long after the initial introduction to the digital microscope. The researcher noted that this change was in instruction; the teacher used the digital microscope in areas that had not been anticipated. Therefore, there was change in instruction that had not been expected and probably could not have been planned previously. This change evolved as the teacher and the students explored the digital microscope and what the possibilities could be.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the use of the digital microscope in new areas that the teacher did not expect and that the digital microscope sustained student interest for much longer than expected. These observations addressed the area of teacher change, which was discussed at length by Richardson (1990; 1991). Richardson noted that teacher change was related to teacher background, which affected the willingness to change. The teacher had expected the digital microscopes to become less interesting to students, but this did not happen. Liem (1987) noted the students continued to be excited in response to teacher excitement, and this appeared to have been a factor here. Digital microscopy was effective in some areas of the curriculum that the teacher had not anticipated. Teacher E's willingness to change and adapt to new situations with the digital microscope was an important factor in their success.

Remarks group E-viii-P6 18 of 27. Teacher E found that in using the digital microscope, the students "learned how to find something under a microscope and [became] easier [to do with experience]." The researcher noted that the students learned how to use a new tool in science, in this instance the digital microscope. The change here was that the digital microscope added a different dimension to learning (how to find something under the microscope). The students were able to move the object and watched the image change in front of them on the monitor. This was a change in the way of learning to use a new kind of microscope. In addition, Teacher E stated that in using the digital microscope, the students "would bring something in … they may have an object that they would bring in to me – 'I want to show you this' … [so], can we get the microscopes out?'" The researcher noted that using the digital microscope caused the students to bring in objects to look at and the teacher was informed of this enthusiasm and interest by what the students did or said. The teacher found that statements such as 'I want to show you this' or 'can we get the microscopes out' informed the teacher that the students wanted to look at something that they found interesting. This kind of learning was student-driven and the students were motivated by what they discovered the digital microscope could do. The change noted here were from a teacher-directed lesson to a student-driven discovery lesson. There was enhanced student interest when selecting something that interested them.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about how students wanted to observe what they wanted to see and asked the teacher if they could use the equipment on their own. This showed a change to student-driven lessons and the desire of students to take out digital microscopes for their own impromptu inquires. As noted previously, Barab and Hay (2001) and other researchers pointed out that students enjoyed a sense of ownership of findings based on inquiry lessons. Crowther (1997) also pointed out that the students internalizing new experiences led to knowledge constructs and the desire to apply their new knowledge constructs. Roth (1996b) noted that it was the principle actors in a classroom community who stimulated discourse and commonly have an uncommon quest to learn. Teacher E was reporting on the actions of principle actors who affected other students in asking for more time with the digital microscope. However, this lesson evolved into one that the students initiated. This student-driven nature of the lessons indicated an effective strategy in the classroom (Crowther, 1997; MacKenzie, 2001). Also, there was the factor of high teacher and student interest and excitement, which was very important in driving sustained student inquiry (Liem, 1987).

Remarks group E-viii-P6 19 of 27. Teacher E remarked about using the digital microscope: “[when] the [microscope lab time] comes around, I really know there … is high interest.” The researcher noted that the teacher related that the students have high interest using the digital microscope. In addition, Teacher E stated that in using the digital microscope, the students “find there is more there than … meets the eye, or, you know, that they could really take time [and see so much more].” The researcher noted that the teacher was informed by what the students did as they used the digital microscope. They found that it was beneficial to not make a decision quickly, but to take a better and – in this instance – closer look. The students connected observing closely with more scrutiny and this was aided by doing this more slowly. To see more closely the students had to observe more slowly. The teacher found that the students discovered that ‘there is more than meets they eye’ or ‘that they could really take time.’ The students connected the concept of taking time with seeing and if they would take more time they would find out when they observed something more completely with the digital microscope. It was a case of ‘more than meets the eye’ instead of a quick look. They should look for a longer time ‘to take a better and closer look’ before making a decision of what they were seeing. The change noted here was the observation by the teacher that the students have a new understanding of how to look closer at something using the digital microscope. The students learned not to make a quick decision about what they were seeing. There was more to see if they took the time to take a better and closer look. The change here was in learning how to see things using the digital microscope to look closely at an object. The teacher changed from telling students to look closely at an object to take time and take a better look, which got better results. The students found that there was ‘more than meets the eye.’

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students gaining the understanding that if they take more time to look, they will see better and closer using digital microscopy. Crowther (1997) pointed out that if there is active cognitive development in a lesson; students tend to learn from their experiences. In this instance, the learning had to do with taking time to look carefully, which was advocated by Liem (1987) in his well-known text on inquiry learning and which was encouraged by Teacher E. In the realm of the art world, ‘taking time to look closely’ was an effective thesis of the widely known artist Georgia O’Keeffe, who painted flowers and shells in large format (as through a magnifying lens) to attract attention to the natural details (Benke, 2000; Robinson, 1989). Teacher E seemed to be advocating a similar approach by encouraging students to take the time to really look at what they were studying microscopically. ‘Close and closer’ was the theme of several popular children’s books, including books by Davidson and Lotus (1993), Rotner and Olivio (1997), and Dabdoub (2003). These books took a simple approach to the wonder of increasingly magnified objects, much the same approach as noted here by Teacher E.

Remarks group E-viii-P6 20 of 27. Teacher E stated that in using the digital microscope, the students “truly … notice things, or learn things, [and they will] bring in an idea or something … and I will say, yeah you know that is right, where have you seen that before?” The researcher noted that the teacher related something that the students brought in or said (or learned) with something that they have seen before. The researcher noted that the teacher reinforced this new learning using a connection to prior knowledge. The researcher noted that the teacher emphasized a belief that to ‘truly have kids notice things,’ what they notice should be supported by prior learning (for example, the teacher remarked ‘you know this is right’ and ‘where have you seen that before?’). The change here was that the teacher connected prior learning with using the digital microscope to lessons where students bring in outside materials for study.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about connecting what students are seeing and discovering to prior knowledge of the student. Connecting what students know with what the students are seeing and discovering is one of the essentials of learning (Crowther, 1997; MacKenzie, 2001). In addition, Pea (1994), Donovan et al. (1998), Lovrich (2004), and other authors had written about how important it is to engage prior knowledge and learning in building new understandings. Also, Roth (2003) also wrote about this scaffolding effect in students' cognitive development in the classroom community. In this instance, Teacher E intuitively drew on this principle and asked students 'where have you seen this before' and encouraged students by saying 'you know this is right.' This type of continual questioning, which was described as mind games by MacKenzie (2001), was a highly effective method of inquiry.

Remarks group E-viii-P6 21 of 27. Teacher E found that in using the digital microscope, the students "have a lot of fun, because … when you are doing money … you can do the coin money [and it interests them] … because you know you can get really old coins and then you [can investigate them]." The researcher noted that the teacher was informed that the students 'have a lot of fun' because the digital microscope allowed them to look at so many things. In this instance, the teacher related to the lesson on coins and remarked that the students not only look at the coins but can find out interesting information from really old coins. The change noted here was that the teacher found that the students have fun investigating really old coins. In addition, Teacher E remarked the teacher needed to "be able to allow the children to investigate and to look closer and to bring in money and to look at [so many things about the coins]." The teacher added that “it is one thing for them to get on-line and pull it up, but [with on-line experiences] they cannot themselves handle it and look at it.” The researcher noted the advantage of the digital microscope which promoted students handling the coins rather than just seeing pictures of the coins. The teacher noted that the students could get things on-line (from the Internet) where they could see pictures and get information. However, using the digital microscopes, the students were able to investigate, to look closer, and to bring in money to study. The researcher noted that the difference in using the digital microscope to do this versus doing research on-line was that ‘they cannot handle it’ (the coins) and cannot ‘look at it.’ The researcher noted that the teacher was informed by what the students did and said that the digital microscope provided a way to see objects up close versus just going to the Internet for information. The researcher noted that the students were able to handle the objects (coins), which the teacher found was so important. Also, the students were able to extend their investigations to on-line resources after digital microscope observations. The change here was the addition of digital technology to what was previously only an on-line investigation.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the importance of manipulating and holding objects that they are studying versus looking up information on the Internet. Jones et al. (2003) addressed the specific issue of holding and manipulating objects in order to better understand them during microscopic inquiry. They called this phenomenon haptic perception, which they identified as key to learning about objects as they are magnified. Related to this haptic perception was the social construction of knowledge by students collectively conducting and sharing in inquiry. In particular, Teacher E's lesson on coins and digital microscopy related to this phenomenon of haptic perception.

Remarks group E-viii-P6 22 of 27. Teacher E found that in using the digital microscope to study U.S. currency, the students "put it on the microscope and turned the bottom light on and you could see it easily … it says: five dollars, five dollars, five dollars." The teacher added that "it magnifies it where it is big enough … you can hold it up to the light [and see the same thing] but if a child does not have really great vision and it is hard, you know." The teacher also added that without the digital microscope, details of U.S. currency are "hard to point out … 'you see it right here?' … and they are holding it up to the light and they are trying to look, but if you just lay it on [the lighted stage of the digital microscope] -- easy, you can see it easy and quick." The researcher noted the importance of the bottom light function on the digital microscope that helped students. In previous lessons without the digital microscope, the students would try to hold currency up to the light and providing that the student had sufficient vision the student would be able to see through the bill and observe markings that were not visible by looking at only one side. The researcher also noted that the teacher noted that 'it was hard to point out.' The teacher was informed by what the students did when the teacher remarked 'you see it right here?' In previous lessons, when the students would hold the currency up to the light, they were trying to see what the teacher was seeing but it was not clear if they did see it. Using the digital microscope the teacher noted that 'you just lay it on there – easy, you can see it easy and quickly.' The researcher noted that the digital microscope allowed the teacher to be informed that the students were seeing something that the teacher wanted them to see and not just having the students 'trying to look.' The change here was that the teacher was informed by what the students were able to see by using the digital microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the students' adaptation to viewing objects with the bottom light, which meant they were seeing through a transparent or translucent object. The students' adaptation to viewing objects in which light passed through them before being seen was an ontological shift of the type that Chi et al. (1994) addressed in their study of the changing view of students as they learned about the natural world. Teacher E reinforced this change in view by showing students what can be seen in this different way of using lighting.

Remarks group E-viii-P6 23 of 27. Teacher E stated that the students' experience "shows the kids that some of the scientists out there may work for years to find out or to see some progress or to make something." The researcher noted that the teacher was addressing how students saw scientists because by using the digital microscope the students were able to relate to scientific research. The change noted here was that by using the digital microscope the students would relate to how a scientist may work for years in close study of something.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about student perceptions of scientists and how long it might take a scientist to do work on a project. Carlson (2001) wrote that young students usually depicted scientists as participating in an activity. Kusnick (2002) also reported young students' preconceptions about science and scientists changed through participation in science inquiry activities. Teacher E found activities using digital microscopy helped the students feel like scientists and gave them a better view of scientific work.

Remarks group E-viii-P6 24 of 27. Teacher E found that, the students' experience "teaches them how to maneuver and how to handle the amount of technology thrown at them." The researcher noted that the teacher connected the term technology to the students using the digital microscope. The change here was that the digital microscope could help students adapt to the new technology that they might encounter in the future. In addition, Teacher E noted that in using the digital microscope, the students saw that it was "interactive" and that they "have instant gratification … because you push a button and something happens." The teacher also remarked that students "have a part of the ownership of it." The researcher noted that this was an important observation. The students using the digital microscope had ownership of their own investigation. This showed a change in that the students felt they had ownership of the investigation and in acquiring knowledge through the interactive functions of the digital microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the digital microscope as an example of new, interactive technology and how that technology benefits the students. Jones et al. (2003) noted the benefits of technology-mediated inquiry in their study of student use of electronic microscopy where the images were viewed on a computer screen. They remarked on how the students' social interaction at the computer monitor and in deciding how to guide the microscope allowed for social construction of knowledge. Teacher E described something similar here with the students and digital microscopy.

Remarks group E-viii-P6 25 of 27. Teacher E found that in using the digital microscope, the students “did a lot of things … getting objects and classifying them, putting them in groups.” The teacher also noted that it was effective “having the kids learn to do [digital microscope activities] in groups.” The teacher asked students “why is this the way you grouped your objects?” To which the teacher recounted that the students responded “well, these have this, and these don’t have this, and these have that … and you know … you do that by just looking at them.” The teacher went on to say the students did “the same type of thing … with the microscope.” The researcher noted that the students were able to explore a variety of objects using the digital microscope and this in turn led to their own classification of objects. The researcher noted that the teacher observed how students tend to group or classify things. The change here was that the by observing the digital microscope activity the teacher was able to find out how students grouped things and was also able to observe how the students worked in groups using the digital microscope. The students informed the teacher of how and why they put things in various groups and this was then extended to forming classifications using the digital microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about how students classified or grouped objects in using digital microscopy and with the unaided eye during a lesson on natural objects. Donovan et al. (1998) and Libarkin et al. (2003) pointed out that organizing things into categories or conceptual groups was an important part of young children’s learning about science and nature. This lesson became open-ended, and as noted previously, open-ended, or divergent, questions in inquiry lessons had been used for some time (Carin & Sund, 1970) and were especially effective because there were a variety of responses, which further stimulated discussion. Teacher E described the students doing these things, verbally, visually, and with the digital microscope's view.

Remarks group E-viii-P6 26 of 27. Teacher E stated that in using the digital microscope, the students were "doing posters and stuff, and they are drawing, and you know, when they are little, the art work is not going to be that great, but this gives them opportunity to print [images from the digital microscope] … you can actually print it out." The teacher added that "you can … help them do more projects, instead of finding it on the Internet and printing out someone else's [research work and images]." The researcher noted that the students produced their own art in a science lesson and were able to 'print it out' using the digital microscope's image-saving software. This was a change in the way the students did their art as part of science lessons. Previously, they had the opportunity to find graphics on the Internet for their projects and printed out someone else's work. The teacher noted that because the children were young, the art work 'is not going to be that great' but with the capabilities of the digital microscope, students would print out something that they found using the microscope. These images became their own products and something that they produced. The researcher noted that there was a change from using the Internet to using their own images in making a poster. Also, the teacher remarked that because the students were young their art work 'is not going to be that great.' The digital microscope allowed the students to find something, to take a picture of it, to print it out, and to draw a picture from the photographic image. In lessons without digital microscopy, the students would draw the object directly. The change here was that the students used photographic skills first rather than drawing skills.

There was also a change in the way the students used the Internet (they did not simply go to the Internet first for graphics).

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about using art in science lessons and the ability to create a student's own art (i.e., digital graphics) using digital microscopy. Wright (2000) discussed the similarities of art and science (both field produce graphics that arouse feelings, but also have deeper meanings) and the role of artistic graphics in scientific presentations. Pestrong (1994) noted that artistic graphics helped hold the attention of students who may not be so much interested in science in particular. Teacher E reported that students used digital imaging in place of artistic drawing or finding images on the Internet and this held their attention and gave them a sense of accomplishment.

Remarks group E-viii-P6 27 of 27. Teacher E found that in using the digital microscope, the students "want to use something new and something different too, for it not to be the same three lessons [again] … because, you know, they will sooner or later [say] 'we have done this' or 'we have seen this' or 'you know, my brother did that.'" The teacher added "so, coming up … with similar types of activities [but] with different items or different objects [is important to students]." The researcher noted that the teacher was informed by what the students did and said that they would wanted something new and different in their activities and not the same lessons. The students informed the teacher by saying: 'we have done this,' 'we have seen this,' or 'my brother did that.' The researcher noted that the teacher revealed something about how children learn – that they needed to be stimulated by new lessons. The change here was in curriculum and lesson planning and that the teacher needed to provide different as well as stimulating lessons for the students to be continue to be interested. The change here also was that the students provided input about the lessons and therefore were part of the lessons changing over time.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students continually wanting something new to work on and objecting if they thought that they may have done an activity before. Roth (1994) and Roth and McGinn (1998) described the effectiveness of student-driven inquiry where students were encouraged to pursue new knowledge for themselves as part of a community of learning. Once the learning took place, however, the driving force of curiosity was diminished (Bell and Linn, 2000). Teacher E might have noted this effect in relating student comments that suggested the students typically wanted to move on to new inquiries and not dwell on older ones or ones they knew of already. Wanting to discover something new was also consistent with the analogy that Roth (1996b) made about how similar an inquiry classroom was to a scientific laboratory.

Interview after first lesson 2004

Remarks group E-viii-A4 1 of 4. Teacher E found that in using the digital microscope, the students were “just experimenting some.” The researcher noted that the teacher observed that the students were doing what the teacher referred to as ‘experimenting’ using the digital microscope. The researcher noted that this was a change in what the students did with the microscope. In previous lessons using the standard light microscope, the students could view what the teacher had selected but with the digital microscope the students would ‘experiment’ (select what they wanted to see), which was an important part of their scientific investigation and inquiry.

In addition, Teacher E found that in using the digital microscope, the students would “watch [other students using the microscope] and then do it [themselves].” The researcher noted that the teacher was informed by observing the students and that the teacher found the students watched and then learned from other students. The researcher noted that the students were learning from each other while using the digital microscope. The researcher noted that this was an important observation by the teacher and it showed that the digital microscope provided a way for students to learn from each other. The lesson was not only teacher-directed but the students were able to watch what the other students were doing. Then, they did it. The change here was that the digital microscope helped other students become mentors to each other and the lesson became more student-directed. The classroom arrangement and set-up helped provide the environment needed for this learning to take place so that the students could easily interact with each other as well as with the digital microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students observing other students working and how that helped the enrichment lessons and how ‘experimenting’ (meaning students choosing what objects to view and under what conditions) was an important part of the lesson. Roth (1994; 1999; 2003) and Roth and McGinn (1998) reported that students naturally worked well together in a community of learning in an inquiry-based classroom where they were free to share discourse (including gestures and body language) and had access to new tools and representational devices. Roth (1999; 2003) noted how similar an inquiry classroom was to a scientific laboratory. Teacher E’s classroom was such a place and the students naturally had discourse and observed one another in the lessons. This interaction promoted phenomenological understandings to arise from the inquiry (Roth, 1999) and community learning to take place. Students' 'experimenting' with selecting and viewing objects was part of this process.

Remarks group E-viii-A4 2 of 4. Teacher E stated that in using the digital microscope, the students "bring in [objects to be magnified] from outside ... again making that connection." The researcher noted that the teacher was informed by what the students did. In this instance, the students brought in objects from outside the classroom. After seeing this, the teacher remarked that they 'made that connection.' The researcher noted that the digital microscope inspired the students' interest to go beyond the classroom and 'connect' with something they saw outside that they would like to see using the digital microscope. This 'connection' was driven by student interest and student inquiry. The researcher noted that this was a change in how the students learned using the digital microscope. Similar learning may have occurred previously using the standard light microscope, but in this instance the teacher observed how the students were learning, what interested them, and how the student 'connection' to something they found interesting in class provided a springboard to further inquiry outside the walls of the classroom.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the importance of a 'connection' to things outside the classroom in the inquiry lessons. As noted previously, Roth (1994) and Roth and McGinn (1998) noted the effectiveness of student-driven inquiry where students were encouraged to pursue their interests in inquiry as part of a community of learning. The 'connection' that Teacher E described, specifically bringing in materials from outside the classroom, was essential to student-driven inquiry because the students wanted to look at what interested them and determined what to study.

Remarks group E-viii-A4 3 of 4. Teacher E noted that using the digital microscope "excited the kids' and "sparked you – watching the kids get excited." The researcher noted that the digital microscope excited both the students and the teacher in response to the student excitement. This interest was 'sparked' while observing the students getting excited. The researcher noted that this excitement between teacher and student was contagious. The change here was that the digital microscope not only sparked the interest of the students but affected the teacher who also became interested while observing the student interest in the lesson.

In addition, Teacher E remarked that in using the digital microscope, the students "get so excited … when [students see things that they] absolutely cannot see with your eye." The researcher noted that the teacher again mentioned how the students were excited about things they would not normally see. The change here was that the teacher was informed that one of the reasons for student excitement was that they are able to see something that was not visible with the unaided eye, yet the digital microscope provided this opportunity. Finally, Teacher E noted that in using the digital microscope, the students "[tried looking at] a thing that you absolutely cannot see with your [eye]." The researcher noted that in observing the unseen the students tested an idea or hypothesis, which was what a scientist would do. In this instance, the teacher was observing students as scientists while they used the digital microscope. The change was that the digital microscope could be used to test something that is not seen otherwise, and the students could investigate and be scientists themselves.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about student excitement and students acting like scientists in studying the materials of the digital microscope lesson. As noted previously, Roth (1994) and Roth and McGinn (1998) noted that there was excitement in student-driven inquiry where students were encouraged to pursue their interests in inquiry as part of a community of learning. As for students acting like scientists, Roth (1999; 2003) noted how similar an inquiry classroom was to a scientific laboratory. Liem (1987) pointed out the contagious nature of excitement in the inquiry classroom and how important it was to driving student inquiry. Teacher E noticed this as well and remarked on it here and at other points in the interviews.

Remarks group E-viii-A4 4 of 4. Teacher E found that in using the digital microscope, the students “felt confident and [were] ... very impressed.” The change here was that the digital microscope made students feel more confident and very impressed with this new confidence. This was a change from using the standard light microscope and following a teacher’s instruction to using a digital microscope and being confident enough for the student to direct their own investigation. In addition, Teacher E remarked that in using the digital microscope, the students showed “interest … enough that they even took [the student's digital microscopy folder] home” to share with parents. The researcher noted that the digital microscope impressed the students enough that they wanted to take the digital folder home. The researcher noted that this was an important connection of learning in the classroom and sharing with the parents at home. It also showed a change in the way a lesson could be taught using digital microscopy and its technology made it available at home. Finally, Teacher E noted that using the digital microscope “just gets them excited.” The researcher noted that the teacher again stated how the digital microscope gets students excited about learning. The researcher noted that this was something the teacher felt strongly about as it was repeated throughout the interview.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the digital microscope getting students excited and that students wanted to take digital files home to show parents their imagery. As pointed out previously, Barab and Hay (2001) noted that students tended to enjoy a sense of ownership of findings based on inquiry lessons. And, Liem (1987) pointed out how important excitement was in driving student inquiry and motivating teachers. A natural extension of this ownership and excitement would be the student’s wish to take home images and discoveries to share with parents.

Interview after lessons 2006

Remarks group E-viii-A6 1 of 13. Teacher E stated that in using the digital microscope, the students “make shapes [as they are] talking about crystals.” The researcher noted that the teacher was informed by what the students did, which was making or drawing the shapes with the crystals, and also by what the students were talking about with the crystals. The teacher noted that the teacher “would have certain groups of kids or certain kids that would tend to drift off or not be interested, but not when you put them on a computer with that type of set-up [the digital microscope], they are interested.” The researcher noted that using the digital microscope allowed for a dialogue between students talking about what they were doing or noticing. The researcher also noted that there was a change in the way students participated in the crystal-making lessons using the digital microscope. The students who may not have participated in the past (the ones that would 'drift off or not be interested') were attentive because they were interested in the computer aspect of the digital microscope and it held their attention. The researcher noted that the change was in student attention to task and was directly related to the students being involved with the technology aspect and the computer functions of the digital microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the response of students who may not have been interested in lessons involving the digital microscope. Roth (1996b) studied the transformation of an inquiry-based classroom by the introduction of a new tool. Roth (1996a; 1996b) viewed the classroom as a community in which there was a network of actors. Principle actors embraced the tool initially, but soon the whole community was caught up in the activity and using the new tool for inquiry. Teacher E described something similar in the classroom where the students who might not be as interested (peripheral actors) were brought into the community of learning by the new tool.

Remarks group E-viii-A6 2 of 13. Teacher E found that in using the digital microscope, the students would "help each other because they would say … 'I found mine like this' [or] 'I found this' [or] 'I looked at this' [or] 'it really looks cool if you do this' [or] 'if you put white paper under it [it looks better that way]." Teacher E added that "they would turn around and say 'it didn't turn out good, so I just tried this' and they are not afraid [to try different things]." The teacher also remarked "they are a lot better than adults [at digital microscopy] – where we are a little more cautious [and tend to] stick with the directions; they would go out on a limb to change something or try something

[new].” The researcher noted that these were examples of how the teacher was being informed about what the students were doing and thinking by their discourse and shared discoveries. The researcher noted that the students used discourse and gestures to point out their discoveries. The change here was that the teacher found out through student discourse and interaction how students shared their discoveries and offered their own ideas for others to try. The students revealed that they were not afraid to try different ways in order to observe the objects better. The teacher noted that the children were not afraid to try something different or change something and did not seem as cautious as adults tended to be.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about how students helped each other by talking about the lessons and pointing to the computer monitors. The student discourse and their gestures aided students in trying new ways to see with the digital microscope. Roth and McGinn (1998) pointed out that students’ use of inscriptions, which would be images of things seen under the digital microscope in this instance, was particularly effective in student learning within classroom communities. Roth (1996b) noted that it was essential for classroom knowledge diffusion to have students engaging in discourse and gesturing and using body language to communicate new concepts as they learned. Teacher E uncovered this effect in the enrichment activities using digital microscopy.

Remarks group E-viii-A6 3 of 13. Teacher E stated that in using the digital microscope, the teacher would “see some of the kids that I didn’t think could work together well, did [work well together and] some of the kids that I thought it would never work [together] … they were fine.” The researcher noted a positive change in student cooperation with each other using digital microscopy. The students who had problems working together in the past were able to use the digital microscope and those that the teacher thought would never work did just fine. So, the change was also in the teacher's expectations of which students would work co-operatively. The teacher found that most students worked well together, which was a change from previous lessons where some of the students did not work well together. In a related matter, Teacher E said that in using the digital microscope, "both girls and the boys liked it." The teacher also remarked: "I don't think there was a [gender] difference." The teacher did not discover a gender difference in using of the digital microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the digital microscope's effect of causing students to work together better and bringing students to work together who would not otherwise do so. Roth (1996b) noted that a new tool can transform a classroom learning community resulting in full participation in inquiry. Roth et al. (1999) reported that students engaged in inquiry in a classroom community where discourse and interaction were going on showed differences in social configurations and connections across groups or between individuals that have different backgrounds and levels of understanding. Teacher E described something similar in this instance with the inclusiveness of the student community as the enrichment class used digital microscopy.

Remarks group E-viii-A6 4 of 13. Teacher E found that in using the digital microscope, the teacher was "able to walk behind them [and] I could watch and kind-of see and I could [observe] – it would give me a heads-up – because when they were on their own individual microscope, I would have no idea what they were seeing but using the computers and the [digital] microscope, where I could at a glance across the room I could see if they were really on task or if they were really getting the objective or if they were not [really helped out].” The researcher noted that this was an important observation by the teacher. This observation addressed the way the teacher was able to observe the students in a much easier and better way. The teacher could ‘watch and kind-of see’ and would give the teacher a ‘heads-up’ in contrast to the individual standard light microscope where the teacher had no idea of what the students were seeing. But using the digital microscope, the teacher only had to ‘glance across the room’ to see if the students were ‘really on task’ or if they were ‘really getting the objective’ or ‘if they were or were not.’ The researcher noted that the teacher was able to notice the students’ engaging in the lessons by just being able to ‘walk behind them.’ The researcher noted that this was a change in the way a teacher found out who was on task, who understood the objective, and who was having trouble. By just checking the monitors, which was possible with the digital microscope, the teacher could see all this. The digital microscope enabled the teacher to be able to see what the students were doing and observing in a more informed way than using the standard light microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about how the teacher was a participant and could see across the room and find out what students were seeing and their understanding of the enrichment lesson. As noted previously, Roth (1994) described how students in an inquiry classroom act much like scientists in communicating their findings and discoveries across the classroom community. According to Crowther (1997), teacher and students could have a partnership in this kind of classroom, which interests both teacher and students. Teacher E mentioned closely following what the students were seeing, which meant the teacher was part of the inquiry process.

Remarks group E-viii-A6 5 of 13. Teacher E stated that in using the digital microscope, the students really “were amazed.” The researcher noted that the teacher again mentioned that the students ‘were amazed’ by what they were seeing. This was a change from previous lessons using the standard light microscope wherein the students were not as enthusiastic as they were using the digital microscope. Also, Teacher E remarked that in using the digital microscope, the students ‘like to save it’ in reference to their digital images. The researcher noted that the students liked the capability of the digital microscope that saved the pictures of what they observed. The change here was that this digital microscope gave the students the option of saving their photographs and other work which they liked to do. The teacher found out that the students liked this function of the computer. In addition, Teacher E noted that in using the digital microscope, the students “learned a lot by watching each other and if they were on just a standard (light) microscope they could not.” The teacher stated again that the students learned from watching each other. The change here was the teacher learned about student interaction and that by watching each other the students learned a lot about the microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about student amazement about what they were seeing and how the students liked to save their work and how students learned from each other during the lesson. As noted previously, Roth (1996b) noted that a new tool can transform a classroom learning community resulting in full participation in inquiry. Roth (1996b) found that initially principle actors made the amazing discoveries, but soon the inquiry spread across the classroom. Roth et al. (1999) reported that students engaged in inquiry in a classroom community where discourse and interaction was going on created a forum for conversation. The desire to keep an individual's own work, an indication of sense of ownership, was discussed by Barab and Hay (2001), who pointed out that students commonly enjoy a sense of ownership of findings based on inquiry lessons. Teacher E described something similar in this instance considering the student amazement, desire to keep their work, and desire for discourse.

Remarks group E-viii-A6 6 of 13. Teacher E stated that in using the digital microscope, the students would "change [the] magnification … it was neat for them to see how just a little bit of change here and there made a difference." The researcher noted that the teacher was informed by what the students found out about magnification and that sometimes just a little change in magnification made a difference in what they were viewing. The researcher noted that there was a change in that students were able to learn a science concept about magnification by using the digital microscope themselves and adjusting it. The researcher noted the hands-on aspect aided students' understanding. Also, Teacher E remarked that in using the digital microscope, the teacher would "watch them make some connections; and it could [connect] back to something else that would support what was going on in the classroom." The researcher noted that the teacher was able to see how students made connections to other curriculum areas in support of what happened in the classroom. The change noted here was that the teacher was able to watch as the students made connections and also as the students drew on other areas for help.

In addition, Teacher E stated that in using the digital microscope, “the students put two and two together.” The teacher added that “the students say ‘oh, look at this’ and ‘look what happened on mine’ and they would compare each others’ [views] and they would wonder ‘why does this look a little bit different?’” This statement was an important observation by the teacher who was informed through the dialogue of the students of how ‘the students put two and two together.’ The students compared their images to other students’ images. This discovery that the students noticed a small difference was important because of the capabilities of the digital microscope, which allowed the students to question, inquire, and to ask why one image was different from another. The discourse among the students helped to spur the discussion and point out a discrepancy. In realizing that there was a discrepancy, the students could then try to find out why, which then led to further discourse, contemplation, and even more questions. The change here was that the digital microscope allowed for students to compare the images that they had with other images by other students, which was not possible with the standard light microscope. The change here also was that the teacher learned from student discourse and their active comparison what they were seeing.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about how students made connections using digital microscopy, including the connection between small movements in instrument settings and large changes in the image and putting ‘two and two’ together about connections with prior learning in other parts of the curriculum. Also, Teacher E spoke about the contradictory observations (i.e., discrepant events) occurring as students compared findings. As noted previously, Roth (2003) and Roth and Welzel (2001) mentioned that scaffolding of new learning upon earlier knowledge is an important aspect of new learning. Herrenkohl and Guerra (1989) expressed the view that the role of metacognitive reflection is important in building understandings in young students. Teacher E noted that students reflected on prior learning in making the connections. As noted previously, Liem (1987) and Appleton (1996) described the many aspects of learning from discrepant events. The discrepant events in this instance emerged unexpectedly from the lesson as students compared findings. The students were faced with the cognitive conflict of selecting magnifications, according to Teacher E. As the teacher noted, the students used social interaction to resolve their questions about what was happening. Teacher E encouraged the students to ask 'why' and to pursue inquiry as an essential approach to inquiry lessons (MacKenzie, 2001). In so doing, the teacher might have fueled the students' desire to seek more answers to their own questions.

Remarks group E-viii-A6 7 of 13. Teacher E stated that in using the digital microscope, the students "shared – 'oh, look what I found.'" The teacher added "with the [standard] light microscope … if someone would bump it, someone would knock it, or [the object] would be lost out from under the microscope." Teacher E noted that in using the digital microscope, the students "take that picture and it was theirs … they could keep if forever … put it in their folder … 'put it in my (slide) show' … [and they would say] 'let me keep this.'" The researcher noted that the teacher was informed by what the students said using the standard light microscope as they shared ('oh look what I found'), however the image could be lost if someone bumped the light microscope, but using the digital microscope, the image could be kept indefinitely. The teacher remarked that 'the students take that picture and it was theirs, they could keep it forever, put it in their folder' and it was permanent. These statements showed a change in the way the students kept what they found. They stored digital images and because of this, the image could be shared and used again in other ways and in other lessons. The researcher noted that the teacher remarked that the students 'take that picture and it was theirs,' which showed that the students had ownership of what they were studying and that the digital microscope, allowed them to keep a record of their investigation. When they 'took the picture,' it became 'theirs.' The students could do a number of things with the captured image. They could keep it forever, put it in their folder (computer), they could put it in a slide show, etc. This showed a change in inquiry method using digital microscopy. Even though the students may have been excited about what they were seeing under a standard light microscope, the image could not have been saved or discussed with others, saved for later to review, etc. where the image could be accessed in other settings such as the classroom or home computers.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about things that gave students a sense of ownership of the things that they discovered, for example, making and storing images 'forever.' As noted previously, Liem (1987) and Barab and Hay (2001) found that students enjoyed a sense of ownership of findings based on inquiry lessons and this added to their sense of excitement and accomplishment. Ownership sense was also cited as one of the benefits of partnership in inquiry-based lessons by TERC and the Concord Consortium (1996). Teacher E remarked here and in other instances about this sense of ownership that the teacher observed among the students with whom the teacher was a partner in their research.

Remarks group E-viii-A6 8 of 13. Teacher E found that in using the digital microscope, the students "build on what they already know and then – hopefully – this kind of makes sense to them … and they all took to it real easily." The researcher noted that the teacher emphasized how the students 'by building on what they already know [prior knowledge],' the lesson 'makes sense to them.' This showed a change in the students' learning. By building on prior knowledge, the students were able to gain an understanding through what they were seeing in relation to what they already knew. The teacher also showed a change in realizing that the digital microscope could connect to what students already know using the computer functions. In addition, Teacher E noted that in using the digital microscope, the students "have high interest … [saying] 'gimme, gimme, gimme' … for days after you do a lesson with it that is all they want to do." The researcher noted that the teacher was informed of the students' high interest in using digital microscopy by what they said and in this case saying for days after the lesson was over that they want to do more lessons using the digital microscope. The change noted here was that the students have high interest when using the digital microscope and showed a change in enthusiasm and interest.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students' building on prior knowledge and having high excitement about what they were discovering. As noted previously, Donovan et al. (1998) and Lovrich (2004) discussed the social aspects of successful inquiry, including the desire of many students to express their excitement of discovery. This sense of excitement being important in driving student inquiry has been discussed by Roth and McGinn (1998) and other researchers. Excitement was essential to the inquiry classroom, according to Liem

(1987); so much so in fact that it was an essential ingredient of such lessons. Teacher E noted the enrichment students' excitement in this instance and has mentioned it many times before.

Remarks group E-viii-A6 9 of 13. Teacher E found that in using the digital microscope, the students "learned real quickly that they could label [images], so the ability to keep [images] and to know what it was [got better]." Teacher E gave an example of a student's remark to another student: "'oh, look, this is [student name]'s picture and he took a picture of [name of object] and he can [keep] it." The teacher added: "the whole record-keeping [process] became so much better, because a lot of times if you were looking at something and they turned [away] and they drew what they saw, you were not really sure if their drawing was really accurate." The researcher noted that the teacher was able to learn quickly by observing what the students said and did during the lesson. The students were able to learn quickly the various functions of the digital microscope's software involving labeling, saving their work, and identification for later use. According to the teacher, the students' discourse included statements like 'oh, look, this is [student name]'s picture of this object,' which helped the teacher find out what the students learned and used during their inquiry. The teacher stated that 'the whole record-keeping process became so much better' and then related this back to a prior lesson. In that prior lesson, the students were doing a similar task but the teacher was not as well-informed because what the teacher observed was 'students were looking at something,' drawing it, and 'not being really sure if their drawing was accurate.' The researcher noted that this was an important observation by the teacher. The importance was in what the teacher learned about what the students saw and what students drew regarding what they were seeing. The change noted here was that with the digital microscope the teacher was informed by being able to compare what the students saw and what they drew. This would not have been possible without the digital microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the students' sense of ownership of research results (images, in particular) and how much better the images are for completing the lessons versus having students draw what they saw. As noted previously, Barab and Hay (2001) described the sense of ownership of findings (in this instance, the images) from on inquiry lessons and how that added to their sense of excitement about the lesson. Liem (1987) described the excitement as essential to inquiry. Pea (1994) described differences in concepts of communications, which would apply to drawing and image making in this instance. Pea noted that transmission and ritual views of communication were more ordinary (in this instance, comparable to sketching or drawing), but that transformative communication (in this instance, digital imaging) changes the perspectives of both students and teachers. Teacher E remarked here that the images (in other words, the transformative communication) was what excited and changed the view of the students and likewise the teacher's own view.

Remarks group E-viii-A6 10 of 13. Teacher E found that in using the digital microscope, the students "bring in what they already know about, say, a video camera, or a still camera or [something else] … different things that they know and try to put [that knowledge] together [with the digital microscope lesson]." The researcher noted that the teacher referred to students bringing in prior knowledge about other technology such as the video camera or still camera and other 'different things they know' and then using this knowledge about other technology and applying it to using the digital microscope. Then, the students were able to put prior knowledge about other technology and new knowledge about digital technology together into ‘a new understanding.’

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students integrating prior knowledge of other digital technology into the lesson on digital microscopy. In earlier instances, prior knowledge meant something students knew from other classes or from other experiences, however in the present instance, prior knowledge relates to student experience with other digital technology. Donovan et al. (1998) and Lovrich (2004) noted that teachers could more effectively teach if they work with pre-existing understandings on the part of the students. Comparing other digital technology and digital microscope, in this instance, was a useful teaching technique for the students. Crowther (1997) discussed students internalizing something new through past experiences and learning from this new construction. Teacher E remarked that the students naturally made this connection with other digital technology.

Remarks group E-viii-A6 11 of 13. Teacher E stated that in using the digital microscope, the students “fill time with just the whole idea of just viewing other people’s samples.” Teacher E also stated that in using the digital microscope, when the students are “doing the lessons … if you are working in your classroom, just make sure you have got groups small enough that everybody gets close enough to a computer.” The teacher added: “because if the groups are too big, [for example] when we were doing [our inquiry] … and there were five kids [at one digital microscope] … they were pouting … but when we were in the computer lab and there [was] one or two kids per microscope [it was much better].” The teacher also remarked: “it works a lot better, when everybody has more ownership in [the inquiry lesson] because they really did a lot more.” The researcher noted the teacher remarked that it was more advantageous for students to work in small groups using the digital microscope. The teacher observed that when the students were able to get close to the computer they were able to do a lot more and could have ownership. When the groups consisted of five students, the groups were too big. In the computer lab, the students were able to work one or two per microscope. The teacher found that this arrangement was a lot better because everybody had more ownership and was doing a lot more. The change here was that the students had ownership of what they investigated and did a lot more when provided by the ability to work in smaller groups (so that they were able to be physically closer to the digital microscope and monitor). In this discussion, the teacher noted the benefit of working in smaller groups.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about the students’ desire to have one microscope per pair of students and the ownership of their discoveries during inquiry lessons. As noted previously, Roth (1994; 1999) noted the importance of student discourse in a classroom community and ready access to new tools and representational devices. Because ready access to new tools and representational devices (in this instance, the digital microscope, the computer monitor, and related computer devices) was probably most important in this instance, pairing of students worked well in the digital microscope lesson, according to Teacher E.

Remarks group E-viii-A6 12 of 13. Teacher E found that in using the digital microscope, the students “work in groups of two per microscope …. [which is] even better than one [student per digital microscope] … because if one kid slips off task or just completely does not understand what you are talking about, the second one usually will pick up on it.” The teacher added that “it also gives them a chance [to say] ‘what about this,’ ‘what if we tried it this way,’ ‘what if we turned it this way.’” The researcher noted that the teacher was informed by what the students did and said when they were paired up for use of the digital microscope. The teacher remarked that ‘two students per microscope’ was even better than one student and it promoted understanding because of student collaboration. If one student ‘slips off task or does not understand’ what the teacher is talking about the other student ‘may pick it up.’ The teacher also noted that the students were given a chance to experiment (‘what about this,’ ‘what if we tried it this way ’and ‘ what if we turned it this way’). Teacher E noted that in using the digital microscope the students “have more conversation and more collaboration.” The digital microscope provided opportunity for discourse and collaboration between students. The teacher was informed by what the students did while they were sitting next to each other through their discourse about what they were seeing. The change noted here was that the teacher discovered by observing the students that the students learned better working in pairs and noted while using the digital microscope the students had discussion and used inquiry-type questions such as ‘what about this, what if we tried it this way, and what is we turned it this way.’ The teacher was informed by observing the students and found out about what kind of questions students asked each other when using the digital microscope, which did not happen when using the standard light microscope.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about students working better ‘with a partner’ using digital microscopy. As noted above, Roth (1994; 1999) and Jones et al. (2003) discussed student discourse being stimulated by ready access to new tools and representational devices. Because ready access to new tools and representational devices (in this instance, the digital microscope and related) was probably most important in this instance, partnering of students worked well in the digital microscope lesson, according to Teacher E. In his book *Nurturing Inquiry*, Pearce (1999) described how every child is a scientist and as such wants to communicate findings with others in the inquiry classroom. This process works much the way that scientists communicate in a laboratory (Roth & McGinn, 1998), and shows the value of having students work in groups or partnering among themselves to 'blaze a path.' Liem (1987) pointed out the many positive benefits of student partnering and working together during inquiry to achieve shared results.

Remarks group E-viii-A6 13 of 13. Teacher E found that in using the digital microscope, the students "work a lot better with two per microscope and the older kids sometimes they just prefer to work together." The teacher added that "I think they like to work with their buddy or somebody but the older ones are much better at labeling and doing the follow-through more so than the younger ones are." The researcher noted that the teacher related what the teacher learned by observing older and younger students. The change noted here was that the teacher was able to observe the students working together and found that there was a difference between what the older and younger students preferred using the digital microscope. Also, Teacher E found that in using the digital microscope, the students "bring in the whole aspect of it being [a] hands-on [activity, for example] when they have a bug or when they have money or just [have] something to handle [the lesson goes better]." The researcher noted that the digital microscope provided hands-on learning when the students bring in something that they were interested in like ‘a bug or money.’

In addition, Teacher E stated that in using the digital microscope, the teacher “noticed that the interest became higher easily.” The change here was that the teacher noted that the digital microscope heightened student interest. Teacher E also found that in using the digital microscope, the students “noticed [more] about science [for example] they might say ‘um, I like it okay,’ but when it was computers and science then it was more interesting all of a sudden, to some of the kids.” The researcher noted that the use of the digital microscope helped make ‘computers and science’ more interesting as compared to what the teacher observed from previous lessons where the student might say ‘um, I like it okay’ about science. The change here was that the students showed increased interest in the science aspect of the lesson using the digital microscope because they were also interested in the computer aspect. Teacher E also remarked that in using the digital microscope, the teacher “noticed that their attitude toward science was better.” The change noted here was increased interest in science because of the higher interest in the computer aspects of the digital microscope, which led to a more positive attitude toward science in general.

In teacher remarks about *students* with regard to the digital microscope, Teacher E spoke about positive attitudes about science and what it is like to be a scientist. As noted previously, Carlson (2001) noted that young students most commonly depict scientists as participating in an activity. Roth and McGinn (1998) found the similarities of student classroom communities engaged in inquiry lessons and the way that scientists in a laboratory go about their work (problem posing, problem solving, and persuading peers).

Teacher E's students who were working with a piece of scientific equipment felt 'scientific.' Teacher E interpreted the enrichment students' comments to mean that they felt this way and felt good about it.

Category – Teacher

Pre-interview 2004

Teacher E expected that in using the digital microscope, the teacher "can help the students better" and "get other teachers to say 'hey, I want to see that.'"

Post-interview 2004

Remarks group E-ix-P4 1 of 1. Teacher E stated that in using the digital microscope, it was possible to "watch the teachers come up with ideas." The researcher noted that there was a change in that the teacher engaged other teachers and collaborated to come up with ideas for using the digital microscope.

In a teacher remark about teacher with regard to the digital microscope, Teacher E spoke about watching teachers come up with ideas for using the digital microscope. Bell et al. (2003) noted that teachers of young children were commonly affected in positive ways by collaboration in reference to new tools.

Post-interview 2006

Remarks group E-ix-P6 1 of 9. Teacher E mentioned that "using the digital microscope made me more familiar with changing up the view on how you are looking at something." The researcher noted that the teacher learned how to operate the digital microscope while using it and became more familiar with the magnification. The change here was that the teacher learned by doing just like the students. In addition, Teacher E stated that using the digital microscope "makes yourself involved in something that creates a circumstance where you are working … it makes …you learn things that [the students] are doing and you understand and it kind of ties things better … as far as having help finding books or finding stuff, that was great.” The researcher noted that the teacher became involved in what the students were doing and that the teacher understood and then things were connected together. The researcher noted that the teacher ‘learned by doing’ and then was able to understand better what the students were doing. The change noted here was that the teacher found it important to be involved and this helped the teacher learn things that the students were doing.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about the learning that the teacher did along with the students and the teacher’s involvement with students as they learned during digital microscope lessons. Bell et al. (2003) noted that teachers were affected in positive ways by collaboration with students in inquiry lessons. Richardson (1990; 1991) discussed teacher change saying that teachers’ willingness to change was related to their background and previous experience. Teacher E, who had a background in computers, was receptive to the changes brought about by digital microscopy. Teacher E expressed that it ‘creates a circumstance where you are working … it makes you learn things.’

Remarks group E-ix-P6 2 of 9. Teacher E found that there was enjoyment in “using the digital microscope – like the art lessons that the art teacher does – I really like [it] when we are doing activities that the kids really [enjoy].” The teacher remarked that the teacher “feels like they make something that really looks nice, looks professional.” The researcher noted that Teacher E found that the students liked to make something that they enjoyed and that looked professional. The change here was that the digital microscope helped to make the lessons ones that the students liked and this led to a change in their work product, which became more professional looking.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about the importance of working on lessons that the students enjoyed. As noted above, Bell et al. (2003) found that teachers were affected in positive ways by collaboration with students in inquiry lessons. One of these ways was satisfaction in the work done by students, which was expressed by Teacher E in the remarks about their work ‘looking nice.’

Remarks group E-ix-P6 3 of 9. Teacher E stated that in using the digital microscope, at one point the teacher “was kind of cautious … I did not feel real comfortable … I was afraid that I might mess them up.” The researcher noted that the teacher was not comfortable with the digital microscope at one point. However, the teacher added that later on the lessons “went fine, and some of them … worked really well.” In addition, Teacher E remarked that in using the digital microscope, students would “see something and they wanted to look at … you cannot go wrong with it … I guess, when we started this, I kept [saying], ‘I do not know exactly what I am going to do with this’ … or, ‘how can this [help].’” The researcher noted that the teacher at the onset of the lesson was not sure about what to do with the digital microscope. The researcher noted that the students looked at something that they wanted to look at and the teacher stated ‘you cannot go wrong with it.’ The teacher stated that the students looked at something they wanted to look at, and the researcher noted that the teacher emphasized what the students wanted to look at and not what the teacher wanted the students to look at during the lesson. This was a change from the pre-interview when the teacher was planning the lesson and had the materials ready for the students to use for the lesson. The lesson became student-centered as well as student-driven over the course of this study.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about the importance of working on lessons that the students enjoyed. As noted above, Richardson (1990; 1991) found that teacher willingness to change is related to teacher background. In the remarks above, Teacher E mentioned initial caution which was replaced by optimism about the lessons and the ability of students to select their own objects for inquiry. Teacher E allowed this change to occur, which was a reflection of the teacher's background in enrichment activities.

Remarks group E-ix-P6 4 of 9. Teacher E stated that using the digital microscope caused the teacher to ask "what if the students asked me a question that I don't know, or what if … the crystals and stuff [do not work properly]." About the 'crystals and stuff,' Teacher E noted "because that was one of the first things [we studied using digital microscopy], it was like 'what if this does not go off right …what if it does not happen the way I want it to happen?'" The teacher also noted "I know this works because I have done it before but yet [I worried], what if [it does not] … I wanted it to work well." The researcher noted that the teacher had reservations about starting to use the digital microscope. The researcher noted that the teacher was worried about not knowing the answers to the students' questions and worried that the lesson would not 'go right' because the teacher did not know the answers as well as not having done the lesson before while using the new equipment (the digital microscope). The teacher could not anticipate what the students might ask. The change here was that the teacher had the confidence to begin to use the digital microscope without knowing all the answers to questions that the students might ask. The lesson could evolve in a direction that the teacher might not have anticipated. This was an important point to consider in lessons that became more student-driven with the teacher guiding the students as they investigated what they were interested in seeing.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about teacher confidence and some initial concerns, including not knowing all the answers and the equipment not working properly. As noted above, Richardson (1990; 1991) found that the teacher's willingness to change was rooted in the teacher's background and experience. In this instance, Teacher E was willing to adapt the new technology to lessons, which the teacher had done before, but not with the digital microscope. Teacher E's computer background may have been a factor here. Teacher E worked with the students and listened to them. Liem (1987) noted that this was important (teacher and student working together) and that teacher enthusiasm was easily conveyed to the students in that way. Rahm et al. (2003) noted the main characteristic of authentic science resulting from student-teacher collaboration was the emergent property of the work, which includes the work becoming more student-driven. What emerged here was a new way of doing lessons where the students brought in things they wanted to study. Teacher E was willing to adapt to this new method as well.

Remarks group E-ix-P6 5 of 9. Teacher E stated that in using the digital microscope, the teacher would "imagine going back to the time when they didn't [use digital microscopy and the teacher would wonder] – 'What would they have done?'" About the older lessons, the teacher added "they will say, 'oh, magnifying glasses,' or just using their own glasses … but for them to imagine … and then imagine where it is going to go from here.” The researcher noted that the teacher asked the students to imagine what it would have been like to go back in time and what would the students have done before any microscope was available. Then, the teacher asked the students to imagine where technology was ‘going from here.’ The students were asked to compare – using the magnifying glasses versus using the digital microscope – and then imagine where technology would be in the future. Also, Teacher E added that using the digital microscope was a way to “think about what they did when they did this, and this, and this, years ago because they did not have these … and I say, ‘no, they did no have these very long at all.’” Talking to students, Teacher E noted that “these are relatively very new - this equipment … and I said ‘now microscopes have been around a while,’ but, this type microscope with the high-technology type situation… I said [this is all new].’” The researcher noted that the teacher compared what the students were familiar with to what was available to the students today and how they could see things more closely. The researcher noted that the comment that ‘they did not have these very long ago at all’ was the teacher’s way of expressing to the students how quickly technology was changing the way they learn. The change noted here was that the teacher was using the digital microscope to represent change and to teach students about how quickly technology is changing.

In addition, Teacher E found that using the digital microscope “teaches them all that basic stuff [and] puts in as much technology, because that is where it is going … it will not stop.” The researcher noted the teacher’s concern for teaching technology and that the digital microscope provided an avenue for learning as much as possible about some new technology that was out there and also preparing the students for a future where there will be even more technology. The researcher noted that this was an important statement about preparation for the students' future. The change noted here was that the teacher used the digital microscope to help students understand about present technology as a spring board to what may be possible in the future. Finally, Teacher E also stated that using the digital microscope enhances "teaching children and training children for jobs that…do not exist yet." The researcher noted that digital microscopy was a way for the teacher to help train students for careers that do not exist yet. The researcher noted that this showed a change in how the teacher prepares students.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about considering new digital microscopy and thinking about the past and future of technology. In these remarks, Teacher E addressed the students, but was also addressing the teacher's own views of changing technology. Richardson (1990; 1991) noted in addressing change, teachers commonly look to the source of the change. In this instance, the source of the change was outside the classroom in the realm of evolving technology. Because of concern about the future of technology, Teacher E asked the students to consider what the teacher knew from personal experience: technology will change in the future and the change will be rapid.

Remarks group E-ix-P6 6 of 9. Teacher E stated that using the digital microscope was a way to "teach and be careful not to say, 'let me do it for you' … because I have done it and I know how to do it … but to tell them, 'move it just a little at a time, scoot it to the side, try backing up from it, you are too close – back up, now do you see it, okay now put it in the center.'" The researcher noted that this was a very important observation, specifically the teacher learned from the students that it was important not to ‘do it’ for the students. The researcher noted that the teacher found it was permissible to tell them how to move the object and how to center it and for the student to try doing it instead of the teacher actually moving and centering the object. It was important for the students to use the equipment and move the object they were observing on their own. The digital microscope made it possible for the student to do the moving because the result was visible on the computer screen and could be verified by the student and the teacher. The researcher noted that the teacher found having the students verify the movement of the object under magnification was important and showed a change in the way the teacher taught the lesson on magnification.

In addition, Teacher E remarked that in using the digital microscope, the teacher “felt some of the frustrations – ‘this does not work right,’ ‘I cannot see it good,’ ‘it does not look clear,’ ‘it does not – you know’ … and then, figuring it out.” The researcher noted that there were still frustrations regarding what the students had to figure out. In this instance, the student had to work out the problem that the image was not clear. The students then had to ‘figure it out’ as a key part of the investigation. The researcher noted that frustration and figuring it out were mentioned together in the teacher’s descriptions of what happened. The frustration of not being able to see something clearly had to be ‘figured out’ by the student on his or her own. The change noted here was that the teacher witnessed what the student was seeing via the monitor of the digital microscope, which was not possible with the standard light microscope. The teacher was also able to observe what the students were trying to make clear; and the teacher allowed the students to resolve the problem. This was an action by the teacher that related to inquiry and problem solution. Finally, Teacher E added that in using the digital microscope, the teacher “gained a lot of insight by watching them … I mean, just being a step back from it [was important].” The change noted here was that using the digital microscope allowed the teacher to step back and observe the students from which the teacher was able to gain insight from watching the students. This kind of observing by the teacher was not possible when the students used the standard light microscope.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about the importance of not ‘doing things for the student’ but instead allowing the student to do those things and listening and observing what the students are saying to the teacher. Richardson (1991) found that experienced teachers perceived information about what was going on in their classrooms differently from less experienced teachers and this affects the way they change their lessons. Teacher E noted here that in the past the teacher might have made adjustments to the microscope for a student, but now the teacher actively resisted doing that. This change likely occurred because the teacher could now see the computer monitors and felt more confident that students could find out for themselves how to focus or move objects. As an experienced teacher, Teacher E also noted the importance of listening and observing the students about what the students were communicating to the teacher about the lesson. This has been a precept of inquiry-based education for some time (Carin & Sund, 1970; Liem, 1987) and Teacher E responded effectively to the students.

Remarks group E-ix-P6 7 of 9. Teacher E stated that in using the digital microscope, the teacher was “going through a program to feel confident enough to teach or help a child with it … just going through the motions myself [helped me].” The researcher noted that the teacher found that it was important to be able to feel confident with the digital microscope. In order to do this, the teacher also had to ‘go through the motions.’ The researcher noted that the teacher realized that in order to help a student, the teacher had to experience what it was like to work the digital microscope for the first time. The researcher noted that the teacher had to learn just like the students had to learn. This made the teacher also a learner in order to help the students as learners. The change here was that the teacher realized that it was important to be a part of the learning experience so that the teacher could be more confident. The researcher noted that the teacher found that it was important to feel confident; therefore it would be important for the students to feel confident also. Also, Teacher E also noted that in using the digital microscope, the teacher “learned a lot of insight by sitting myself down and going through every little portion of the microscope to feel like I have done it.” The researcher noted that this was an important statement – in order for the teacher to have insight into how the students learn or perceive something the teacher had to ‘go through every little portion of the microscope to feel like I have done it.’ Finally, Teacher E added that in using the digital microscope, the teacher was “guiding them in good microscope maneuvers that will help them no matter what they are putting under there.” The researcher noted that the digital microscope helped the students learn about digital microscope technology and once they learned the correct ‘maneuvers,’ they could apply this new learning in ways ‘that will help them no matter what they are putting under there.’ The researcher noted that the lesson was an important stepping stone to understanding how to use the digital microscope or any microscope.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about the importance of the teacher mastering the digital microscope in order to teach the students. Teacher E's mastery of digital microscopy represented a change for the teacher because this technology was not in the classroom before this time and having the digital microscopes as part of the lessons was voluntary. Richardson (1990; 1991) attributed teacher willingness to change to the teacher's background or personal history. Teacher E was computer-oriented based on past experience, so the transition to digital microscopy was in keeping with the teacher's interests. Richardson (1990; 1991) found that experienced teachers assess change based on some specific criteria, including how the change will fit into the teacher's classroom situation. For Teacher E, this fit was likely viewed as positive. Teacher E was willing to spend the time necessary to learn the new technology and adapt it to the existing lessons and make new lessons also.

Remarks group E-ix-P6 8 of 9. Teacher E stated that in using the digital microscope, the teacher could "teach a lot about squares and rectangles because of [the comparative shape of] buildings … those are easy shapes and you can see them in real life, all over the place … every now and then you might see some fancy window that is octagonal shaped or some building that is not just a typical square or rectangular … but, everything as you look around the room is pretty much a rectangle or square, you know, the bricks, everything." The teacher added "and then, you know, so it is easy to turn around when you are teaching that, [because] when you are teaching something that is different and odd, or different and [for example] the crystals – to me, [that] made a big impression on me … because it was like, it is right here, look, and look at every one of them this way … it is not by chance, that's in the [crystal's] design." The researcher noted that by using the digital microscope the teacher learned something about teaching geometrical shapes that the teacher had taught before – in this case squares and rectangles. The researcher noted that the teacher mentioned teaching something ‘that was different and odd’ in this case ‘crystals.’ This connection made a significant impression on the teacher, because ‘it was right there.’ The teacher then realized that it was not by chance, that it was in the crystal’s ‘design.’ The teacher had an ‘aha moment’ that brought things to mind that were previously known to the teacher, but known in a different way and with a different understanding. The researcher noted that the teacher learned something and was struck by it. The researcher noted that this marked a change in how the teacher perceived something in nature (crystals), which the teacher had taught previously but now saw in a totally different way. The teacher saw this in a different way because the digital microscope provided the teacher with a new way to see crystals up close and they were ‘right there.’ The researcher noted that this ‘wow moment’ for the teacher was very important. It denoted change in the way the teacher perceived nature and then taught a lesson that had been done before, but was now given with a different understanding. Also because the teacher had this revealing moment, the teacher might be able to observe a similar ‘aha moment’ among the students when they might see something they had seen before but with a new understanding of what they are seeing. The researcher also noted that the teacher was very descriptive when telling about this experience and was very aware of the details of this experience, which provided this insightful moment. The change here was that the teacher became more informed of what was observed and this was made possible because of the digital microscope.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about how the teacher’s view of something in nature, in this instance – crystals, was changed profoundly by looking at them using digital microscopy. According to research literature, a teacher's important learning moments might come from an external activity, workshop, or collaborative work with a scientist (Lane, 1996b; Lawless & Rock, 1998; Rahm et al., 2003). In this instance, Teacher E described such a learning moment when preparing the lessons on crystal growth.

Remarks group E-ix-P6 9 of 9. Teacher E stated that using the digital microscope was a way to "do it yourself and you take the pictures … you know it is for real … that is truly the way it happens … and I can prove it by the students saying 'here's my pictures.'" The researcher noted that the digital microscope had the capability of providing a proof of what was seen because it could capture an image and then 'you know it was for real.' The 'proof' students had was in showing others – 'here's my pictures.' This capability allowed the student to 'do it themselves' and then verify it with a digital product. The researcher noted that the teacher's comments showed a change in the way a student could 'verify' what he or she found. Further, this allowed the students to be in charge of their own investigation and then have the capability of being verified by images, which then could be shown to other students and the teacher. The researcher noted that digital microscopy allowed students to be able to investigate on their own what interested them and also allowed for verification without hindering the investigation. Also, Teacher E added that using the digital microscope was a way to know "how to focus and how to feel more comfortable with it in general." The researcher noted that the teacher was concerned with student confidence in general and their focusing in particular. Therefore, by using the digital microscope the students gained the skill of focusing on an object and by doing this became more confident with using the digital microscope. The researcher noted that the change here was that in learning a skill, it helped with confidence. Finally, Teacher E found that using the digital microscope was a way to “do your labeling on the computer or by hand or whatever but this gives them the opportunity … and we have not done as much [of this] as I would like.” The researcher noted that the digital microscope allowed the students to use computer graphics aspects of the digital microscope to label images and do this as much as is needed. The change here was that the digital microscope’s computer functions enhanced learning microscopy but at the same time reinforced student computer skills.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about being able to verify findings with digital images, being confident with the digital microscope, and using the digital microscope functions to label images. Teacher E described how the teacher adapted to the new technology and how that solved pre-existing problems with some activities. Richardson (1990; 1991) expressed that the key to understanding teacher change was teacher background and experience. In this instance, these were problems that Teacher E had encountered in past lessons, which were solved with digital microscopy. So, the adoption of digital microscopy was a change that Teacher E embraced.

Interview after first lesson 2004

Remarks group E-ix-A4 1 of 1. Teacher E stated that using the digital microscope “[the teacher] gets excited too.” The researcher noted that the teacher was excited about the digital microscope lessons. The change here was that the teacher became enthusiastic about the digital microscope and not just the students. In addition, Teacher E noted that using the digital microscope “makes me [the teacher] feel good.” The researcher noted that the teacher ‘feels good’ using the digital microscope, which showed that the teacher was confident about using the digital microscope and using it in lessons for the students. The change here was that the teacher began using the digital microscope with some apprehension (as noted in the pre-interview 2004) and now the teacher related that apprehension had been replaced with confidence and satisfaction.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about enthusiasm, excitement, and confidence about the digital microscope and the associated lessons. Riggs and Enochs (1990), Levitt and Manner (2001), and Bell et al. (2003) noted that teachers were affected in positive ways by collaboration, in partnerships, and by the introduction of new technology. Somewhat like the effect of introducing new tools to students in an inquiry classroom (Roth, 1996b), the teacher also was positively affected by these changes. Liem (1987) noted that the excitement described here was essential to effective student inquiry. As Richardson (1990; 1991) pointed out, the extent of change in teacher behavior was related to teacher background and experience. Richardson (1991) remarked that previous work suggested that teacher beliefs were closely tied to their own perception of themselves as students. In this instance, we could see how digital microscopy affected Teacher E and this was likely related in part to the teacher's background and experience in computer technology.

Interview after lessons 2006

Remarks group E-ix-A6 1 of 10. Teacher E stated that in using the digital microscope, the teacher "feels more secure about what I [am] doing, so the more I had to back up what I was doing [the better]… because a lot of times kids will ask a question that you may or may not be ready for, but having the preparation made you feel more secure about using the microscope." The researcher noted that the preparation for the digital microscopy lesson was an important part of the teacher's feeling secure using the digital microscope. The change here was that the teacher became more secure about answering student questions, especially if the teacher had sufficient preparation time so that the teacher could 'back up' what the teacher was doing. By 'back up,' the teacher was saying that gaining background knowledge of the lesson being studied was important during the planning phase of lessons.

In addition, Teacher E stated that using the digital microscope was a way to "have high [interest] and I mean always [have high interest] … some of the kids that I would expect to be more off-task or (have) a behavior problem definitely [work on digital microscopy with only] a little direction, I mean, I had very high success [with these students]." The researcher noted that the teacher found that all the students – even some that the teacher anticipated that would have behavioral problems – had a high interest in digital microscopy and they had a very high level of success in these lessons. The researcher noted that this was a change in this teacher's view from earlier interviews when the teacher described some students that were 'off-task.' Now, the teacher mentioned that by using the digital microscope all students were interested and on-task. Finally, Teacher E added that using the digital microscope "broaden[ed] what I understand and how… where I was not real comfortable with microscopes myself, I mean, I have used them some times [in the past] … but, I found out how using them [worked well]." The researcher noted a change that by using the digital microscope, the activity broadened the teacher's understanding and helped the teacher feel more comfortable using microscopes.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about needing more preparation time (but feeling more confident about the digital microscope technology and teaching with it) and having high success with using digital microscopy. The change reported by Teacher E would fall under the category of first-order change according to Richardson (1990). First-order change relates to trying new kinds of activities. Richardson (1990) gave questions that teachers asked themselves before making a change: who was in charge of this; what was the focus; and what was significant and worthwhile about it. For Teacher E, the teacher was in charge and the focus is using digital microscopy, and the third question was answered in part by Teacher E's remarks here. Even though the teacher wanted more preparation time (something not under the teacher's control), the significant and worthwhile aspects were addressed when Teacher E had more confidence and higher success.

Remarks group E-ix-A6 2 of 10. Teacher E stated that in using the digital microscope, the teacher "learn[ed] a lot about file management … and saving files, moving files, adjusting different [files] … it is like 'oh, this is the same as the other' [in comparing file-saving methods] … and the more practice you have at saving things and file management, the better you get at it." The researcher noted that the teacher learned about file management, a computer function, using images created by the digital microscope. The teacher was able through practice to get better at saving files and general file management. The researcher noted that the change was in using the digital microscope – the teacher was able to improve on computer skills including file management skills by using the computer function of the digital microscope. Also, Teacher E noted that using the digital microscope was a way of "professionally being able to share with other teachers or … [a way of] telling them 'it is not that hard' … you want to [share with them] … [a] fifth grade teacher came [to me] and she got the [microscopes] and we set up four computers in a room [for her] and then we got the stand-alone big screen and she was using that for a display and she had …success and she has had very little time with it." The researcher noted that the teacher was able to share professionally in the teacher's digital microscope experience and with other teachers. The teacher instructed other teachers and stated that it was 'not that hard' while showing the teachers. Teacher E became more confident with using the digital microscope and then was able to share this confidence with other teachers and encouraged the other teachers to try using digital microscopy also. The change noted here was that the teacher developed confidence by using the digital microscope enough to share with other teachers and found that it 'was not hard.'

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about change in the level of the teacher's computer skills as a result of digital microscopy. Teacher E's remarks were about another first-order change (term of Richardson, 1990) in computer skills related to digital microscopy. The large number of digital files (images and videos) that the teacher and students could produce using several digital microscopes over several lessons could be enormous. Teacher E noted that the file management was one thing that the teacher had to learn to do. As with all first-order change, the teacher in this instance was motivated to make the change because the teacher's background and experience made this change seem worthwhile.

Remarks group E-ix-A6 3 of 10. Teacher E found that using the digital microscope was a way to "keep adding one more something that we can use them with … another area, another lesson, another grade level that has something that would be interesting [to students].” The researcher noted that the teacher planned on using the digital microscope in other areas, lessons, and grade levels. The researcher noted that the change here was one of curriculum and curriculum planning. The teacher was looking ahead for places where the digital microscope might be able to be used. There was the present change in curriculum using the digital microscope and there was also the future potential to change the curriculum using the digital microscope. In addition, Teacher E stated that using the digital microscope was a way to “realize how much the kids were going to enjoy using [the digital microscope] just as an art tool … that was kind-of like an added bonus to the side.” The teacher went on to say that digital microscopy was a way to “find out [something] about using the microscope that we did not expect to learn [which] was that in digital blue there is an art [connection] that you could use … [to] change the background, or you could change the image [and] … that is where we do the labeling and whatever.” The researcher noted that the teacher never realized how much the students would enjoy the art functions of the digital microscope. The change here was that the teacher discovered something about the interest of the students and that the digital microscope provided a bonus with this capability that included an art component as well as labeling.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about new areas of the curriculum for future digital microscope use, including the art-related functions of the digital microscope. This represented another type of possible first-order change (term of Richardson, 1990) having to do with future curriculum change regarding digital microscopy. In a related matter, Teacher E spoke about art-functions of the digital microscope. As Richardson (1991) pointed out, a teacher's willingness to change in this way was closely related to the teacher's perceptions of self as a learner or the teacher's perceptions of students. As with all first-order change, the teacher in this instance was motivated to make the change because the teacher's background and experience made this change seem worthwhile.

Remarks group E-ix-A6 4 of 10. Teacher E found that using the digital microscope "led into a comfort zone … so when they were using it, actually doing magnification and looking at specimens, you know, [I] felt more comfortable." The researcher noted that the teacher again referred to a 'comfort zone' and that it was important for the teacher and students to feel comfortable when they were using the digital microscope. Teacher E also noted that using the digital microscope was a way to "watch them become more familiar with the program, playing under an idea of doing art, but then they began understanding the program better and feel more comfortable with it." The researcher noted that the teacher was able to observe that as the students became more familiar with the digital microscope, in this instance the art function, the teacher observed that the students understood the program better by 'playing under an idea of doing art.' Both the teacher and the students became more comfortable with the digital microscope. The change here was that in using the digital microscope the teacher could observe the students and saw how they became more familiar with the program. When the students 'played' with the art function, it actually helped the students understand the program better. With this understanding, the teacher and the students became more comfortable with the other functions of the digital microscope.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about observing students and how this helped the teacher and students to become more familiar with the digital microscope and how to do the lessons. Most researchers viewed a partnership as involving an entity outside the school (Spencer et al., 1998; Tinker, 1997), however Marek (2002) noted that a partnership was "a symbiosis where each entity gains greatly through collaboration." In this sense, the partnership between the teacher and students, which was mentioned here and many other times in these interviews, was just as real as other kinds. Liem (1987) noted that teacher-student working together was essential in inquiry lessons and noted how enthusiasm and guidance was conveyed in this way. Teacher E spoke about both the teacher and students learning at the same time about digital microscopy and related inquiry and this qualified as a real partnership of learning. In this process, the teacher gained as much as the students. This idea of teacher and students working together has been around for a long time (Carin & Sund, 1970), probably because it worked so well. Carin and Sund (1970) quote ancient Roman philosophy in saying "*qui docet discit*," he who teaches, learns.

Remarks group E-ix-A6 5 of 10. Teacher E remarked that using the digital microscope was a way "[for me to] become more familiar [with computer programs] … [in] helping the kids … and even [for] myself." Also, Teacher E stated that using the digital microscope is a way "[for me to] teach them about getting closer up to something." Teacher E also found that using the digital microscope was a way "[for me to] teach them about the [standard light] microscope … it is very similar." The researcher noted that the digital microscope helped the teacher instruct the students also about the standard light microscope. The researcher noted that the digital microscope was a teaching tool as well as an instrument used to see things more closely.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about how the teacher became more familiar with the digital microscope-related computer programs, teach about microscopy in general, and use the digital microscope to get closer and closer to objects. In these remarks and earlier ones as well, Teacher E remarked that the teacher studied the digital microscope first, thought of lessons, and during the lessons formed a partnership with the students in learning about digital microscopy and how to observe closely during lessons. This partnership was a type of symbiosis, which was the prime characteristic of a learning partnership in the view of Marek (2002, p. 1) and the mark of an outstanding teacher according to Liem (1987). Teacher E also drew on background knowledge to help build the lessons. Teacher E's digital microscopy lessons achieved a similar effect that was seen in the immensely popular book for children called *Close Closer Closest* (Rotner & Olivo, 1997), which explored students' views of perspective and scale. By presenting progressively closer views of things that young children encounter every day, Rotner and Olivo showed how the viewer's perspective and understanding can be changed. Teacher E described something similar in this instance. The lessons helped students learn about microscopy in general, even light microscopy, by using the digital microscope, an related effect discussed in detail by Davidson (1995–2004).

Remarks group E-ix-A6 6 of 10. Teacher E found that in using the digital microscope, the teacher noticed that the students "like that control … [saying, for example] 'I can do it the way I want to do it' … and 'it's not bad.'" The researcher noted that the students had control and ‘can do it the way that I want.’ The teacher stated that ‘it’s not bad’ that the students can control the digital microscope on their own. The researcher noted that giving the students control of their own investigation was a change in direction and classroom management by the teacher. Previously, the teacher set the rules of what to observe and helped students in being able to view what was placed under the standard light microscope. The digital microscope provided an avenue for the student to be in charge of their own investigation by its simplicity of operation and its being child-friendly. The researcher noted that the teacher in this response found the students have the ‘control’ and conveyed with the statement ‘and it’s not bad’ that the teacher was not quite sure what to expect. The researcher noted that the teacher’s lessons changed from teacher-directed to student-directed by giving the students control of what they want to observe.

In addition, Teacher E stated that using the digital microscope was a way to “be able to put more underneath our lesson, underneath our umbrella … we have lots of different things going on at once.” The researcher noted that this was a change in being able to use the digital microscope to build on other lessons. The teacher mentioned that there were ‘lots of different things going on at once’ and the digital microscope helped this happen. The researcher noted a change in depth and content of specific lessons and being able to have an ‘umbrella’ that covered more instead of one single aspect of the lesson (as in using the standard light microscope and viewing one microscope slide).

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about the teacher’s support for student-driven investigations and having lots of activities for students. Teacher E’s change to student-driven inquiry was a type of teacher change that Richardson (1991) described as understandable in view of a teacher's own perception of the teacher as a learner. In other words, Richardson's view was that a teacher like Teacher E felt that student-driven inquiry would work well for the teacher, so why not the students. Teacher E in a similar way followed the prescription of Roth (1996b) in having inquiry lessons around a new tool. Students in control of their own learning has been a long-standing concept in inquiry-based lessons (Crowther, 1997; Liem, 1987), which has been shown more recently to be accelerated by the inclusion of special tools and representational devices for student use (Jones et al., 2003; Roth, 2003). Teacher E made use the digital microscope in this instance and then gave the students their conversation space and tool space (Jones et al., 2000) to do their work and pursue their interests with the enrichment lessons.

Remarks group E-ix-A6 7 of 10. Teacher E found that using the digital microscope "reinforces [the lesson] but it was also showing them how things go together … it's not math over here and science is here and social studies is here … [but rather] all of the different areas of education or with learning or with life fit together." The researcher noted that this was a very important statement: the teacher found that the digital microscope reinforces and also shows students 'how things go together.' The researcher noted that the digital microscope lessons provided for an integration of different subjects and that this in turn showed that learning was not 'just a little piece here and there.' The researcher noted there was a change in how the digital microscope affects the classroom by incorporating different subjects that each reinforced the learning in the lesson.

In a teacher remark about *teacher* with regard to the digital microscope, Teacher E spoke about how the digital microscope lessons showed the teacher and the students how the many fields of study fit together. In discussing teacher change, Richardson (1991) noted that it was important to look at what teachers think and believe in order to understand their willingness to change and how they change. For Teacher E, the interconnectedness of different curricula may have been an underlying thought or belief, but in the inquiries associated with digital microscopy these underlying issues emerged. Thoughts about interconnectedness of disciplines (holistic learning) commonly emerged during wide-ranging inquiry lessons (Liem, 1987), and the teacher's willingness to embrace these connections and to share them with the students enhanced the lessons.

Remarks group E-ix-A6 8 of 10. Teacher E stated that using the digital microscope was a way to "look and see who was getting what and I sometimes I would have to re-direct this one – 'okay, you are missing what we are doing here' … because, I could see what they were seeing." The researcher noted that the key phrase here was that the teacher 'could see what they were seeing.' The researcher noted that the digital microscope provided the teacher with the ability to view many students' monitors at once and then to be able to find who understood and who needed help. The researcher noted that this marked a change in the way a teacher observed what the students were seeing. As a result of the new technology, the teacher had the ability to multi-task and to help students. In previous lessons using the standard light microscope, this would not have been possible. Teacher E also remarked that using the digital microscope was a way to "see where they were going with what they were looking at or what they were taking pictures of." The researcher noted that the teacher again stated that the digital microscope allowed the teacher to see what the students were doing, in what direction they were going, and just what interested the students. The researcher noted that this marked a change in how a teacher observed students and provides for better input on the interests and direction of the students during the lessons.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about being able to see what all the students were doing during digital microscopy lessons. Teacher E noticed that all the computer monitors in the classroom could be seen by the teacher, and the teacher could monitor what the students were seeing from one point in the room. This affirmed to the teacher the practical and significant difference of seeing the monitors versus older methods of monitoring student progress. Being completely engaged in the students' progress was an essential part of effective inquiry (Lansdown et al., 1971; Liem, 1987; Pearce, 1999). Because of its practicality and usefulness (Richardson, 1991), Teacher E was willing to use the new technology in order to multi-task observation and instruction in the inquiry classroom.

Remarks group E-ix-A6 9 of 10. Teacher E found that using the digital microscope was a way to "do some of the art things that we did [where] they could share some of their creativity … and [with an image] say 'this is how I came up with this.'" The researcher noted that the digital microscope provided a change in how students were able to share their creativity. It provided an opportunity for discourse on how 'the students came up with this.' The researcher noted that the teacher mentioned how the students used the digital microscope to do 'some of the art things,' 'creativity,' and 'how I came up with this,' all of which shows a change in what a lesson on microscopy could provide using the digital versus the light microscope.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about encouraging creativity, including doing artistic work, during digital microscope lessons. For Teacher E, encouraging creative work, particularly artistic work, was somewhat of a change. Richardson (1991) described this type of change as having much to do with “the teacher as a person.” Teacher E felt that this kind of expression was important and when digital microscopy made this a practical extension of the activities being done, the teacher encouraged the enrichment students to be creative and artistic.

Remarks group E-ix-A6 10 of 10. Teacher E found that using the digital microscope was a way to “share with me [saying] ‘oh, look what I took this picture,’ [and to say] ‘I saw it this way.’” Teacher E added “and the next kid beside him [or her] may take the same exact object, take a picture or see it a whole different way and to say this is not wrong.” The teacher went on to say: “they are both doing what I asked them to do, but it may [work differently for each], just in their own view.” The researcher noted that the students were informing the teacher by what they said as well as what they did. In this instance, the student stated ‘oh, look what I made’ and ‘I saw it this way.’ The change here was that the teacher was informed by what the students shared observing similar things. This helped the teacher to see what the students were seeing by having the students share what they found interesting about the same object or same photograph. The teacher was able to learn about student creativity and how the students came up with their ideas. The change in this case was very important and critical the way the teacher found out how the students saw things more closely. In observing this, the teacher was informed by the interests and saw in a ‘whole different way’ and ‘without being wrong.’ The latter statement of ‘not being wrong’ was very important and provided a safe environment for the learners and showed that there was not just one way of seeing something. In the teacher’s view, what each learner found was equally important. Also, student discourse informed the teacher that there were individual differences that were not obvious from viewing alone but rather from discussion of what they were viewing.

In addition, Teacher E stated that using the digital microscope was a way to "use something that we used on the [digital] microscopes that we have saved or we bring it up, save something, and then we could import it into Photodraw … and it is just like 'ooh!' … and some of them you could import it this way but not the other way … some of it moves from one medium to the other easily." The researcher noted that there was a change in that the teacher was more specific about the program that was available to use with the digital microscope. The students informed the teacher by what they said and did and in this instance there was something remarkable like 'ooh!' The teacher was informed that the students were interested in what they were seeing. The researcher noted that the digital microscope was also a learning tool that helped students use other computer functions such as Photodraw, saving things, retrieving files, and importing programs, all of which showed a change in instruction and combination of microscopy and computer technology.

In teacher remarks about *teacher* with regard to the digital microscope, Teacher E spoke about: the teacher being informed about the different things that the students were doing during the lessons on digital microscopy; how it was important that the students were not viewed as 'wrong' in their observations; and the relationship of student interest level and creativity. As noted previously, Teacher E formed a type of partnership with the students in learning about digital microscopy and how to observe closely during lessons (described by Liem, 1987; Marek, 2002; and others). In this partnership, the teacher listened closely to the students and watched them – and vice versa, which Pearce (1999) pointed out as essential in nurturing inquiry. Teacher E noted that students' observations were just that – observations – and that none were wrong. Liem (1987) described this approach as essential to effective inquiry lessons. Students expressed their creativity by using some graphics programs with the images they made, which indicated some higher level thinking and skills among the students (Phillips, 1994). Teacher E expressed these actions among the students using more specific terminology than previously, suggesting teacher development in this area as well.

Remarks of Teacher A

Teacher A, an elementary (K–5) art classroom teacher, was interviewed using the approved pre/post-interview and after-lesson interview question sets that are reproduced in Appendix B. Relevant background on Teacher A and the teacher's classroom description are located in Appendix C.

The researcher's data archives contain transcript sources and semantic domain coding files for all the quotations in this section. Transcripts with remarks of Teacher A have the following archived sources (in parentheses): pre-interview 2004 (A-NB2-1), post-interview 2004 (A-NB2-2), post-interview 2006 (A-NB2-3), interview after first lesson 2004 (A-NB2-4), and interview after lessons 2006 (A-NB2-5). Files related to the semantic domain coding of teacher remarks have the following archived sources (in parentheses): pre-interview 2004 (A-NB3-1), post-interview 2004 (A-NB3-2), post-interview 2006 (A-NB3-3), interview after first lesson 2004 (A-NB3-4), and interview after lessons 2006 (A-NB3-5). The reference codes mean, for example, A-NB2-1, Teacher A's notebook number 2, tab number 1. See Appendix D for more on these reference codes and an inventory of the researcher' archived data.

Numerical Summary of Remarks Across Semantic Domain Categories

Figures A10 and A11 (Appendix A) are histograms showing the relative number of Teacher A's remark groups across semantic domain categories for pairs of interviews that used the same questions. Figure A10 shows that there were at least a total of two remark groups for Teacher A under each of the nine semantic domain categories when the post-interviews of 2004 and 2006 are combined. For these two interviews, most remark groups are under the categories *teacher* (10) and *characteristic* (8). Figure A11 shows that there were at least a total of two remark groups for Teacher E under seven of the nine semantic domain categories when the interview after first lesson 2004 and the interview after lessons 2006 are combined. For these two interviews, most remark groups are under the categories of *students* (11) and *teacher* (8).

Remarks Organized by Semantic Domain Categories

Category – Characteristic

Pre-interview 2004

About the digital microscope's characteristics, Teacher A predicted that the digital microscope would be "such a valuable tool" and "a sophisticated looking piece of equipment" that is "user friendly." Because it comes apart, it "is going to be an asset." Also, the teacher anticipated that the digital microscope "says touch me, look at me…the color, the shape, it just screams for children to come and explore! … it is almost like a 'candy bar' yet saying, 'do not touch it yet.'"

About the students' view of the digital microscope's characteristics, Teacher A remarked that even though the digital microscope may be "user friendly" the students will need time to "play with it." Also, the teacher responded that perhaps the students would want to "make music to go with the flow of the lines [of the image]" or "write music to it" or "write about it [the image] in literature and English."

About the teachers' view of the digital microscope's characteristics in lessons, Teacher A stated that the whole class and the teacher being able to "see it [the images] at the same time on the screen" and "see what everyone is seeing all at the same time" were also important characteristics.

Researcher summary (characteristic) from pre-interview: In remarks coded in the category *characteristic*, Teacher A spoke about what the teacher expected that the students would see and do using the digital microscope. With regard to the digital microscope and its characteristics, Teacher A spoke about a valuable tool, which was sophisticated and user-friendly, that will be an asset. The teacher mentioned the visual appeal of the instrument. With regard to students' views of the digital microscope, the teacher mentioned that students would want to play with it and make music with it and write about it. With regard to the teacher's view of the digital microscope in lessons, the teacher mentioned being able to see what all students were seeing at the same time as a valued asset.

Post-interview 2004

Remarks group A-i-P4 1 of 5. Teacher A responded that the digital microscope "invited them [the students] to explore" and that "it invites you [the students] to touch it, to try it" and that "it screamed for the kids to touch it." For this teacher, the students were motivated by its appealing look, had their interests aroused, which would then lead to exploration. The researcher noted that the digital microscope motivated students' curiosity by students trying out the various functions of the digital microscope.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about student interest driving the inquiry and the visual appeal of the digital microscope. Herrenkohl and Guerra (1998) and Pearce (1999) noted how groups of students could build knowledge and understanding if given the proper tools and learning situations and time to think about what they are doing. Krajcik et al. (1998) emphasized the project-based nature of such learning situations, which was evident in the art projects discussed by Teacher A. Roth (1996b) discussed learning environments and how they were transformed by using a single new tool. The transformation noted here was provided by the digital microscope and the resulting student-driven inquiry on digital microscopes.

Remarks group A-i-P4 2 of 5. Teacher A stated that it was important for the students to be able to "take the microscope out of its stand…and be able to put it on something large or away from the stand or plate" and then "photograph what they were seeing." The computer-related aspects of the digital microscope allowed the students to "look with the microscope, do some magnification, and then take a picture" which then "several students could view the object that was being shown." It was important to have "enough of the microscopes to have at least two students to a microscope in a lab [setting]." These statements reflected what this teacher believed was an important part of learning using the digital microscope. In this case, at least two students shared a station and viewed an image at the same time. The researcher noted that the ability of the students to capture what they saw was important so that other students as well as the teacher could share in the discovery.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about collaborative learning and the teacher being a participant in student discoveries. As noted above, Herrenkohl and Guerra (1998) and Pearce (1999) noted how groups of students could build knowledge and understanding if given the proper tools and learning situations and Roth (1996b) described remarkable transformation in an inquiry class when a new tool was introduced. Roth (1994) examined the effect of a representational device upon an inquiry classroom and noted that the students communicated very effectively and a learning community was established. Teacher A noted that students collaborated among themselves and thereby actively influenced the lesson.

Remarks group A-i-P4 3 of 5. Teacher A stated that the set up of the microscopes "was not a big deal" and was "not a burden." These statements showed that the set up process and time involved were important things to be considered in using equipment in an art classroom that had a tight schedule that must be followed.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about the digital microscope being easy to set up. Teacher A's willingness to use the digital microscope in the teacher's art lessons represented a significant teacher change. Richardson (1991) noted that teacher change was related closely to the teacher's background and personal history, but might have to do also with cues from the organizational environment. Richardson (1991) noted that teachers are more receptive to change when there was a practical reason for the change, the change fit their teaching situation, and the costs were reasonable. In this instance, Teacher A remarked indirectly on the first two of those items. Bell et al. (2003) reported positive changes in teachers as a result of collaboration with students, which were also evident here, and Liem (1987) noted that teacher participation during inquiry lessons was essential for effective outcomes.

Remarks group A-i-P4 4 of 5. The digital microscope "invited the students to explore," which was a connection to hands-on learning and the opportunity for students to choose what to explore. In previous statements, Teacher A noted that the digital microscope "wasn't intimidating" and that the microscope be "user-friendly." The "students wanted to see what (the digital microscope) would do" and because it was "kid-friendly" it "let them see parts that they wouldn't normally see." Because the microscope was "pretty kid-friendly, user-friendly, even for me, and for the children, so that it made you want to do more with it." The use of the words 'want' and 'see' and 'do more', in this instance, allowed for the investigation and exploration to be driven by the students. As Teacher A observed, the students "want light here and light there" and "when they found something really, really neat they could take a picture of it." The researcher noted that the teacher was able to observe how students saw something closer as they changed the light source when viewing an object. The researcher noted that the use of the phrases such as 'not intimidating,' 'pretty kid-friendly,' and 'not be a burden,' showed what, in this instance, was important to the success of implementing the digital microscope in an art class. Also, the researcher noted that the digital microscope's being user friendly provided a safe environment for both the student and the teacher and led to being an invitation for exploration initiated by the students.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about the invitation to explore given by the digital microscope and the child-friendly aspects of the digital microscope. Roth (1996b) described the transformation of an inquiry classroom due to the introduction of a new tool. Roth noted that the transformation and rapid student adoption of the new tool occurred because of students' discourse and interaction surrounding the new tool. The child-friendly aspects of the digital microscope likely aided this transformation, but also appealed to the teacher. As Richardson (1991) pointed out, practical matters such as the child-friendly aspects in this instance were factors in the willingness of teachers to embrace change in the classroom. As noted previously, Bell et al. (2003) reported positive changes in teachers as a result of collaboration with students, which was also evident here, and Liem (1987) noted that teacher participation during inquiry lessons was essential for effective outcomes.

Remarks group A-i-P4 5 of 5. Teacher A stated that being a "digital kind of component versus just the traditional, being blue and plastic and therefore very inviting, … the ability to have students call you over and see their screen instead of having you [the teacher] look down the optic part … to see the picture they took … to look right here or see this right on that screen seeing the image … right in front of you on the screen helped too … the hands-on, activity part … was very beneficial." The teacher found that digital microscopy encouraged the children "to just get a better grip on what they were seeing" and "explore a little more" and "be a fun component but a brain teaser kind of thing." These comments showed that the very nature of this digital microscope intrigued the students, piqued their interest, provided a "new tool and just the exposure of a new tool" let the students "see what they wouldn't normally see," and "be a digital kind of component versus just the traditional [microscope].” The researcher noted that the teacher thought that characteristic of the blue color of the digital microscope was appealing to students. Also, the researcher noted that exploration by students led to discovery, driven by where the students wanted to go, using not a toy but something that could be fun to use. This, in turn, led to exploration by the students on their own, driven by their own curiosity, and sharing in the discovery with other students.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about how the digital microscope encouraged exploration by the students and how easy it was for the teacher to see what the students were observing. As noted above, Roth (1996b) described the transformation of an inquiry classroom due to the introduction of a new tool. Roth noted that the new tool stimulated exploration by students and student discourse on what was occurring. The students’ exploration using the digital microscope was part of this transformation, which was witnessed by the teacher. As Richardson (1991) pointed out, practical matters such as being able to see the computer monitors and to better guide students’ inquiry in this instance were factors in the willingness of teachers to embrace change in the classroom. As noted previously, Bell et al. (2003) reported positive changes in teachers as a result of collaboration with students, which was also evident here, and Liem (1987) noted that teacher participation during inquiry lessons was essential for effective outcomes.

Post-interview 2006

Remarks group A-i-P6 1 of 3. Teacher A responded to what the digital microscope could do and how it integrated into the art lesson by “using the drawing components of the program … they would flip on a certain thing that it would make it flip colors and it would become really like an Andy Warhol kind of painting or something else." The teacher commented about the software related to the digital microscope saying: "The students were able to use the other drawing components and the filming components that I had not played as much as I would like to," which showed something the teacher was learning which was that the students were selecting the computer part of the microscope for their own observations. Teacher A commented that the digital microscope gave the students "more choices," allowed the students "to take the microscope out of the holder, "were able to take the microscope out of the stand so that they could put it up against an object." The researcher noted that this showed how the students had become more familiar with the microscope and its computer component even though the students were in the same age group as the previous two interviews. The researcher noted that the teacher was no longer focused so much on the actual physical characteristics of the microscope such as color but more on the characteristics of the microscope and the software programs that it connected with and what the students could do with the programs.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about students using the computer-related software components for artistic enhancement of the digital images and how they enjoyed doing this as they explored. For Teacher A, encouraging students to create artistic images using the digital microscope's graphic software was a change from lessons of the past. Richardson (1990; 1991) found that teacher change is closely related to the teacher's beliefs, attitudes, goals, and knowledge. The change noted here is what Richardson (1990) called first-order change, or change in activities but not in the curriculum. Teacher A was open to this change (using the digital microscope and its graphics software) and described the results in artistic terms (‘flipping colors’ and ‘making an Andy Warhol kind of thing’).

Remarks group A-i-P6 2 of 3. Teacher A noted that the students “put the microscope where they wanted to see – not what the stand determined they would see,” which led the way to a more open-ended lesson. The teacher commented again that the students “put the actual microscope part up to whatever it is they wanted to look at.” The researcher noted that the teacher realized that this was a hands-on activity and that the students were in control of observing something that interested them. Teacher A added that the students could “move themselves and the little objects and get up there rather than a traditional [light] microscope that makes you put it under that little space and roll it down.” The teacher saw that this may have been a problem with a standard light microscope (not being kid-friendly would mean that rolling down to focus and putting something under the microscope to view was easier with this digital microscope). The researcher noted that the students were more in control of what and how they see.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about students looking at what they wanted to see using the digital microscope. This was in turn related to the more open-ended nature of lessons. As noted previously, Roth (1996b) described the transformation of an inquiry classroom due to the introduction of a new tool. Roth (1994) found this to be particularly striking when the new tool was a representational device. Roth (1994; 1996b) noted that the new tool stimulated exploration by students and student discourse on what it was that they were seeing. This led to the students’ interests and what they wanted to see to driving the open-ended lesson.

Remarks group A-i-P6 3 of 3. Teacher A commented that the students "could share so easily with their friends and say 'hey, come look' and the child did not have to look in [the eyepiece of a microscope], they could look at the monitor." The researcher noted that the ease in sharing each others' discoveries was important to the teacher and showed a change in student interaction where students shared what they were interested in, which was now possible with the image being viewed on a monitor for all to see. This was in contrast to the standard light microscope where the image could only be viewed one student at a time with an image that may or may not have been the same for all viewers.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about students sharing discoveries, student discourse, and the teacher's participating in the students' inquiry and discovery. Roth and McGinn (1998) discussed the remarkable student discourse about shared discoveries that occurred in an inquiry classroom when students were allowed to interact and explore. They refer to inscriptions, which were broadly defined as visual representations of nature, as being the center of student discourse. They viewed the inquiry classroom as being much like a scientific or engineering laboratory where groups of professionals were discussing and working on problems and making discoveries. Teacher A observed this occurring in the art lessons using digital microscopy and acted as a participant in the students' exploration and discourse.

Interview after lesson 2004

Remarks group A-i-A4 1 of 2. Teacher A made comments on the topic of characteristic such as "having this image as a reference" and "having something they saw that is captured as a photo." The researcher noted that these comments showed that the digital component of this microscope was important for the lesson. In addition, Teacher A found that the digital microscope "allowed students to really concentrate on the part that they wanted to really be looking at, to be able to take a picture, to have that picture in their hand to look at, and then be able to do their work [from it for an art lesson]." The digital microscope "helps to block out things around" like the art view finder did but because it is a microscope it is meant to "zero in on a certain part." The researcher noted that this made a direct comparison to the artist's view finder that the art students normally used in art lessons. Not using the artist's view finder but instead the digital microscope improved quality of their work. By taking a picture of what they were seeing and preserving that image in the photo, they were able to do the art lesson better. The students were using an image that was captured rather than a view finder image that was seen. The researcher noted that this was a comparison to what they usually do after viewing with the art view finder (they go back and draw what they see). So, the digital microscope improved the quality of work. The view finder was still used in art lessons, but is now reinforced with another view with the digital microscope, which has the capability of photographing the image the students wanted in their work.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about the digital microscope's ability to focus student attention on specific parts of the object and the lesson associated with the object. In the past, Teacher A had used a simple artist's view finder to narrow the students' focus on objects, but the digital microscope served that function in the inquiry lessons. Wright (2000) noted that in studying natural materials for their scientific and artistic qualities, the focus should be on mixing the material qualities and an inner vision (what the qualities mean or convey). The microscope helped focus those qualities in the minds of the students (Davidson, 1995-2004). That Teacher A was receptive to changing the method of viewing objects closely was an aspect of teacher change. The change noted here was what Richardson (1990) called first-order change, or change in activities but not in the curriculum and was likely related to the teacher's experience that caused the teacher to be open to such change.

Remarks group A-i-A4 2 of 2. Teacher A stated the digital microscope was "handy and easily taken to the classroom" and could be stored away in a container on the desk but still remained "hooked up to the computer so that it can be used easily." The researcher noted that this showed how this teacher viewed the characteristics of the digital microscope as well as its ability to be stored away when not in use but still readily accessible. The teacher added that the students "learn the mechanics of how it works" and learn that "I [the student] am in control … [the student] selected exactly what to show the viewer." In addition, Teacher A saw digital microscopy as "making it user-friendly for the teachers … using clear plastic tubs that were numbered to correspond to the microscope … everything has the same number … the container allows the [digital] microscope and the operating disk and the microscope tools to be together … acting like a little kit … again showing that this kit makes it easier for a teacher to access … the [digital] microscope can lay flat and they can be stored and stacked." The researcher noted the importance of the consideration of space in a classroom and the ease of using the instrument in a classroom art setting. Finally, Teacher A noted how important it was to "take the microscope apart and use it," "explore with the microscope," have "the ability to see something up really close," and "set up as a station with one computer and microscope per table."

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about the ease of use of the digital microscope by teacher and students and the student's control over what to view with the digital microscope. In discussing teacher change, Richardson (1990; 1991) noted that primary considerations included practicality and suitability. In these remarks, Teacher A touched on those points in affirming the use of digital microscopes in the art lessons. Student control over what they looked at and how they see it was likely deeply connected to a sense of ownership of the inquiry results (Barab & Hay, 2001) and to the sense of excitement that students felt (Liem, 1987) using the digital microscope, as noted by the teacher.

Interview after lessons 2006

Remarks group A-i-A6 1 of 2. Teacher found that digital microscope was so inviting to students that "you have to put it away because if the students see it, they want to mess with it, because it really invites the child to come and explore, which is great." Teacher A stated that "set up is important" and "being able to put it away from view but still [being] easily accessible" was also important and the digital microscope being 'accessible … [but] out of view' showed that the digital microscope had a visual appeal and, having this, the children wanted to use it.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about the ease of use of the digital microscope. As noted above, in discussing teacher change, Richardson (1990; 1991) stated that two primary considerations were practicality and suitability. In these remarks, Teacher A touched on those points in saying how well the digital microscopes were suited to the art lessons.

Remarks group A-i-A6 2 of 2. Teacher A responded that the physical aspects of the microscope invited students to want to “mess with it.” The physical aspects of this microscope, Teacher A noted, “invite the child to come and explore…which is great!” and “[by] being user-friendly and visually inviting to children, it is an invitation to explore.” This visual appeal then led students to want to ‘mess with it,’ which in turn then invited the students to further explore which the teacher noted that ‘it was great.’ The researcher noted that Teacher A found that it was important for students to want to explore, but not necessarily know that they were exploring. Students, at first, wanted to ‘mess with it’ or ‘play with it,’ which led to exploration and in turn led to their understanding of some component of the lesson.

In teacher remarks about the digital microscope and *characteristic*, Teacher A spoke about how the digital microscopes invited students to explore with them. Teacher A remarked on the visual appeal of the digital microscope, which was important in an art class. Pestrong (1994) found that visual appeal was important in attracting and holding students’ attention, whether this was related to the materials studied or the equipment. Wright (2000) noted that students were attracted to the art qualities of natural materials, which Teacher A observed as well.

Category – Comparison

Pre-interview 2004

About the digital microscope and comparison, Teacher A anticipated that it will give students a new and different view of art objects in that it “shows them things with a whole different set of eyes.” The teacher expected that digital microscopy “[will] show them things they see everyday with a whole different view.” The teacher expected that if “students get to use it again and again they are going to think that is pretty cool” and “I’ll bet if I do this it is sort of like students just have building blocks to keep building on.” The teacher added that it “is like prior knowledge…you know the students are going to have that now to build on from here on and my goodness look at how young they are.” The teacher also anticipated that “this microscope as a tool for science is important.” The teacher expected that students will “look at things in shape and form and color and texture and all the things that we study.”

Researcher summary (comparison) from pre-interview: In remarks coded in the category *comparison*, Teacher A spoke about what the teacher expected that the students would see and do using the digital microscope. The teacher mentioned students having ‘a different set of eyes,’ thinking it is ‘pretty cool,’ and students building on prior knowledge using the digital microscope. The teacher also mentioned a ‘tool for science’ and the digital microscope’s use in art to look at ‘shape, form, and texture.’

Post-interview 2004

Remarks group A-ii-P4 1 of 1. Teacher A compared all its features and found that the digital microscope “allowed more flexibility than a traditional microscope would allow.” The researcher noted that here flexibility means to the teacher that students are free to do more things with the digital microscope than with a standard light microscope, including making images.

In teacher remarks about the digital microscope and *comparison*, Teacher A spoke about the flexibility of the digital microscope, which referred to the many uses and modes of use of the device. As noted previously, Richardson (1990; 1991) identified practicality and suitability as two important factors in a teacher's decision to embrace change in the classroom. Here, Teacher A referred to these factors in remarking on change that the teacher has embraced.

Post-interview 2006

Remarks group A-ii-P6 1 of 1. Teacher A compared the digital microscope to the standard light microscope and remarked that "you cannot take a fresh flower and put it underneath because it will squish and it just does not allow it" … "the light source and the size [are] the main issues." The researcher noted that the teacher compared the advantages of the digital microscope in that the teacher could use fresh flowers more easily, there was better lighting of the objects, and size of the object being view was not a restriction (because the digital microscope could be taken out of the stand and used in hand-held mode on a large object).

In teacher remarks about the digital microscope and *comparison*, Teacher A spoke about placing a fresh flower under the digital microscope and using the lighting and hand-held modes of the digital microscope. Davidson (1995-2004) noted that the hand-held mode was a remarkable feature of the digital microscope. As noted above, Richardson (1990; 1991) identified practicality and suitability as two important factors in teacher change in the classroom (in this instance, changing the equipment used in the lessons). Teacher A wanted students to observe fresh flowers up close and the digital microscope afforded this opportunity.

Interview after first lesson 2004

Remarks group A-ii-A4 1 of 2. Teacher A compared digital microscopy in several ways saying "when you give children a flower – or anything to look at – and you say look at it closely, well they will stick it right up in their face … that does not do what I am getting at … I have tried view-finders, which is a very traditional tool in art, [it] is a piece of paper with a square cut in the middle … and you use it to sort of hold in or out and closer to your eye and farther away and the purpose is to help you block out things around." The researcher noted that Teacher A changed from using the view-finder, a very traditional tool in art, and one that this teacher used before, to the digital microscope. Teacher A observed that in prior lessons when asked to look closely at an object the students would stick it right up to their face. In addition, the teacher found that the students "now look at shape, form, color, and texture and other things that they study in art [and use the digital microscope] to look more closely." The comparison of using the digital microscope to the view-finder in art was important in that the teacher revealed how the view-finder used in previous art lessons helped to see things more closely and related that to how the digital microscope helped the students see. The teacher found that the digital microscope could help the students look closely at an object without 'sticking it right up to their face' in part because the image could be shared with the students. This could not be done previously even though the view-finder had the same purpose of holding in or out, closer and farther from the eye, and blocking out things around it. The digital microscope provided an important stepping stone in that it could be monitored by the teacher as well as viewed by the students. The digital microscope then provided a leap in understanding of a science concept – how to see something more closely - by being able to show the students what the teacher meant when the teacher asked them to ‘look more closely.’ The researcher noted that this was an important finding in the category of comparison, because it showed how the teacher was able to get students to understand what it meant to go about ‘the how to see’ something more closely, which included the shape, form, color, and texture of an object. This showed what could be achieved with the technology of the digital microscope.

In teacher remarks about the digital microscope and *comparison*, Teacher A spoke about how the digital microscope compared to the artist’s view finder and what children did when the teacher asked them to ‘see up close.’ Regarding the change aspect of these remarks, Teacher A’s willingness to change from the traditional artist’s viewfinder to the digital microscope’s view in some student art lessons was likely rooted in the teacher’s background and the teacher’s perception that this new technology was practical and suitable for the planned art lessons (Richardson, 1990; 1991). Jones et al. (2003) noted that using microscopes with this kind of technology changed students’ perceptions of everyday objects and encouraged students to make artistic representations. Teacher A likely wanted to change the students’ perspectives in addition to doing art lessons. Rotner and Olivo (1997) produced a book from a child’s perspective with step-wise views of increasing magnification (titled *Close Closer Closest*). The book showed that beyond ‘holding it close to your face,’ the next step was magnification. Teacher A’s instruction to ‘look more closely’ was a study in perception and scale, as was the book by Rotner and Olivo.

Remarks group A-ii-A4 2 of 2. Teacher A compared the digital microscope lessons to the way that Georgia O’Keeffe did her art saying “like O’Keeffe said, it makes you stop and it makes you look at it [the art] whether you want to or not." The teacher stated that like the artist Georgia O'Keeffe, "the digital microscope draws you into that for the moment … and that is what she would say … she wanted people to stop and look … and it sort of demands that you do … when you see images you cannot just [say] 'oh, that's a flower' … you know, you [say] '*wow, what is that …that's a flower*!'" The researcher noted how Teacher A compared O'Keeffe's work to the digital microscope's images. Teacher A also stated that "it makes the image stick in your mind a little more versus 'oh, that was neat.'" The researcher noted that this compared the artist who wanted to have people be drawn in by her art (Georgia O'Keeffe) with the digital microscope and its ability to help a student see something closer in more detail. Teacher A noted that by using the digital microscope an object such as a fresh flower could be viewed with a better light source and did not have to be restricted in size to fit under the microscope and not be damaged. The comparison between the digital microscope and the standard light microscope allowed the teacher to include objects that could not be used in the lesson before. The lesson was changed by the introduction of the digital microscope to include a larger variety of objects that could be viewed with a better light source and more flexibility. The images on the screen made the students and other observers stop and look like Georgia O'Keeffe's art work did.

In teacher remarks about the digital microscope and *comparison*, Teacher A spoke about the digital microscope's view and how it compares to the view in the art works of Georgia O'Keeffe. As noted above, Jones et al. (2003) noted that using microscopes with this kind of technology changes students' perceptions of everyday objects and encourages students to make artistic representations. The Georgia O'Keeffe style of art, which depicted natural objects – especially one or two flowers – at much-larger-than-life scales was pioneered by O'Keeffe in the 1920s when the artist had the vision to make 'paintings big so that onlookers would be surprised' and would take time to look closely at them (Benke, 2000). Teacher A's vision was to use the digital microscope to achieve the same point of view about flowers and other natural objects in the art classroom. Teacher A's willingness to use the digital microscope in some student art lessons related to Georgia O'Keeffe was likely rooted in the teacher's background and the teacher's perception that this new technology was practical and suitable for this purpose (Richardson, 1990; 1991).

Interview after lessons 2006

Teacher A made no coded comments in the category *comparison* during the interview after lessons 2006.

Category – Computer

Pre-interview 2004

About the digital microscope in relation to the computer, Teacher A anticipated that the digital microscope "captured that [image]" and "took [remarkable] pictures with the computer." Also, the teacher expected that the teacher expected to use the digital microscope to "click it on and start taking it through the simple little screen and showing everything I think they are just going to ask such as 'can you look at bugs, can you put water in.'"

Researcher summary (computer) from pre-interview: In remarks coded in the category *computer*, Teacher A spoke about what the teacher expected that the students would see and do using the digital microscope. The teacher spoke about capturing images, taking remarkable pictures, and getting started by ‘clicking on it.’ The teacher expected that the students would ask about looking at objects like ‘bugs.’

Post-interview 2004

Remarks group A-iii-P4 1 of 1. Teacher A stated that the students liked to “mess with all those features that it had” and that students generally liked taking pictures with the digital microscope. Teacher A found that “you need to let students use all those options” and “students need a little [more] time with some of the options to manipulate their pictures of the images that were captured by the digital microscope.” Teacher A felt that it was important to be able to use the digital microscope to do a demonstration that “you could hook it up to a screen.”

In teacher remarks about the digital microscope and computer, Teacher A spoke about how the students liked to ‘mess’ or ‘play’ with the digital microscope and its computer components and that they needed time to do this in order to do their art lessons with the digital microscope. Roth (1996b) and Jones et al. (2003) also found that students need time to freely explore with new tools and interact with the tools and each other during technology-mediated inquiry. This was especially important when students were dealing with things that were beyond their everyday perception (Jones et al., 2003). Teacher A was willing to allow the students to do this and encouraged them to ‘play’ or ‘mess’ with the digital microscope and its software components.

Post-interview 2006

Teacher A made no coded comments in the category *computer* during the interview after lessons 2006.

Interview after first lesson 2004 and Interview after lessons 2006

Teacher A made no coded comments in the category *computer* during the interview after first lesson 2004 and the interview after lessons 2006.

Category – Connection

Pre-interview 2004

About the digital microscope and its connection, Teacher A anticipated that it could be used "to encourage the exploration of our art environment." The teacher also expected that digital microscopy would give "insight into how an artist might see or think just like a scientist … how does a scientist see or think and why do they think this way." The teacher went on to say that digital microscopy would "help students understand a different path that maybe they wouldn't normally think about because they are going to have a tool to enhance it versus not ever having that [kind of microscope]."

About the digital microscope and its connection with students, the teacher anticipated that it would help "because this microscope has allowed them a little peak into a scientific realm," and that it was "going to be like a door that maybe they might not have opened." The teacher predicted that digital microscopy was "going to start a lot more curiosity perhaps not for everyone but I think a greater percentage because they will have had that opportunity."

About the digital microscope and its connection with art standards, the teacher added that "art standards talk about size comparison, and form and all kinds of things." The teacher also mentioned that using digital microscopy will "enhance state standards in art;" it will enhance "art, science, health [look at foods], in any social studies they could look at different artifacts…and could benefit something in any area [of the curriculum]."

Researcher summary (connection) from pre-interview: In remarks coded in the category *connection*, Teacher A spoke about what the teacher expected that the students would see and do using the digital microscope. With regard to the digital microscope's connections, the teacher spoke about insight (an artist's and a scientist's) and having a different understanding. With regard to the connection with students, the teacher mentioned 'peaking into the scientific realm,' and 'opening a door' for students. With regard to art standards, the teacher added that the digital microscope will help enhance state art standards and art connections with other academic areas.

Post-interview 2004

Remarks group A-iv-P4 1 of 3. Teacher A spoke about numerous connections of the digital microscope saying that the teacher was "learning how to hook the digital microscope to other subject areas all together." Teacher A stated that the students "did science and art but … writing … math … and all those could have been pulled in also." The researcher noted that the teacher was speaking about bringing in new areas of the curriculum with the digital microscope. In addition, Teacher A spoke about connections in saying that the students have "[now used] a tool that scientists normally would use in a different area." Teacher A stated that when "a new component is added to something you normally do, it opens up all these options." Teacher A noted that the students now said "'could we get out that viewer, microscope, or whatever they've used – and do it with this' because they remember that [the new tool] allowed you to do a certain component of art." The researcher noted that this showed how students are building on prior knowledge and adding to that knowledge.

In teacher remarks about the digital microscope and *connection*, Teacher A spoke about how the students enjoyed working with digital microscopy and the many connections that were possible using digital microscopy. As noted previously, Roth (1996b) described the transformation of inquiry classrooms when a new tool was introduced. From Teacher A's statements not only was the classroom community of students changed, so was the nature of their investigations and the teacher's point of view as well. Richardson (1990; 1991) addressed teacher change and pointed to teacher background as a key element in the willingness of teachers to change. Teacher A's noted that in trying something new opened up new options. With this view in mind, Teacher A was open to the use of the digital microscope. As Roth (1996) pointed out, there was no way to know what the effect of a new tool was going to be, so Teacher A could not have known it would be a success when starting to use the new tool.

Remarks group A-iv-P4 2 of 3. Teacher A stated that for "the art objectives – a lot of it is working with technology and, even with this being a digital microscope, [using] that component in composing sort of a picture as they were looking under the microscope." Teacher A concluded: "they could decide what magnification they wanted to look at, they could move it around, [and] they could decide what side [they wanted to see]." The researcher noted that the teacher mentioned art objectives (standards) and how the digital microscope would fit into the technology part of the standards. Teacher A also mentioned how the students took charge of manipulating the digital microscope.

In addition, Teacher A remarked that "in the teaching aspects, the elements of art, principles of design, [they] were all there because it enhanced the textures of things the kids wouldn't see, the colors, or the shapes." Teacher A mentioned that the students learned to “pick out these little components of the elements of art and the principles of design.” This teacher noted that digital microscopy “tied two areas together, which you never can go wrong, so it helped a lot with that part.” Teacher A viewed digital microscopy as a “benefit to science and art specifically.” The researcher noted that the teacher brought out how the digital microscope brought together areas of the art curriculum and the science-art benefit of the digital microscope. Teacher A stated that using the digital microscope to explore things like ‘texture in art’ helped to make kids excited about science and helped them realize that technology like the digital microscope had a place in art too. The researcher noted the connection between science and art, and the excitement that came from the use of the digital microscope and the materials in an art lesson on texture. This was a key statement that discovery could happen using a scientific tool such as the digital microscope in an art class in a lesson on textures. The connection here was opening the students’ eyes (discovery) and the connection between an art lesson and the discipline of science. The researcher noted the connection here was in the ability to gain information about the parts of the flower through the connection of the art and the science, which was science interwoven with the color and shapes in art and then looked again through the lens of science. Science and art were interwoven in the detail of the parts of the flower as well as the colors and shapes, and like the texture that the teacher was trying to have the students see, complemented each other. The science and the art were united to inform the students about texture.

In teacher remarks about the digital microscope and *connection,* Teacher A spoke about how students used higher level thinking skills when they used the digital microscope to compose an image, how students made their own decisions during inquiry lessons, and how students' use of the digital microscope helped integrate the fields of art and science in the teacher's art lessons. Higher level thinking skills – Piagetian operational functions of thinking (Bosak, 1991; Phillips, 1993) – manifested in the art students' manipulation of the digital microscope (artistically composing the image) and processing the imagery (artistically interpreting the photomicrograph). Teacher A encouraged the art students to make their own decisions about what to image and why, and the students responded by helping to take charge of the direction of their own lessons (Liem, 1987). In the process of doing this lesson, both teacher and students gained insight into the interconnections of art and science, which had similar roots in the meaning of graphic representations (as noted by Pestrong, 1994 and Wright, 2000 – among other authors).

Remarks group A-iv-P4 3 of 3. Teacher A stated "with the art it really met a lot of art standards and objectives with the elements and the principles." Teacher A found that using digital microscopy "gave the students a good introduction to how that would be [in other words, students as scientists]." Teacher A wanted "to continue on with the study of Georgia O'Keeffe," saying the digital microscope method is "such a twist to art." The researcher noted that digital microscopy met some state standards, helped students be like artists and scientists, and helped achieve a 'twist' to the art lessons regarding Georgia O'Keeffe. In addition, for Teacher A, students "[were] able to make a connection of the … artist planning part that I don't know if they have had that experience before." This teacher added that "because they could take something that was really pretty small that would fit under the microscope and select a view like an artist would and be able to share that with whoever else was looking either by taking a picture or making a piece of art."

These comments showed how Teacher A viewed the students working like real artists with the digital microscope. The researcher noted that the teacher viewed the planning part of art work using digital microscopy to be a new experience for students, an important experience.

In teacher remarks about the digital microscope and *connection*, Teacher A spoke about how the digital microscope helped students see images of natural objects as an artist would, particularly the artist Georgia O'Keeffe. Benke (2000) noted that the artist Georgia O'Keeffe wanted to make small things like flowers larger so that people would notice them in her paintings and begin to think about them. Teacher A had much the same objectives with the students, but also wanted the students to see things as Georgia O'Keeffe did. The change for the teacher was not in the objectives of the lesson, but in the tool used. This is a type of first-order change that Richardson (1990; 1991) described as easy for teachers as long as considerations like practicality and appropriateness to the situation are met.

Post-interview 2006

Remarks group A-iv-P6 1 of 2. Teacher A stated that digital microscopy lessons had "a strong writing component" and that students "[were] able to describe, and use words to describe what they are seeing, not just with their eyes." Teacher A went on to say that there was a connection where the students "do a lot of math, recording measurements and things like that." Teacher A remarked that students could "write, paint, draw, and do any part in art" with digital microscopy. The researcher noted that the teacher spoke about the interdisciplinary connections that digital microscopy had to writing and mathematics, painting, drawing, and other areas of art. In addition, Teacher A wanted students to “explore texture more … be able to draw it.” The teacher also wanted students to “start looking at nature … everywhere.” Teacher A had a higher success rate in directing children through studying artists and the artists’ techniques and by “just learning to observe and being able to draw textures and other things like that.” The researcher noted that the teacher wanted students to explore more and ‘start looking at nature,’ which was one of the goals of the artist Georgia O’Keeffe when she started painting large, close up flowers and shells.

In teacher remarks about the digital microscope and *connection*, Teacher A spoke about how the digital microscope art lessons were naturally connected to writing, mathematics, measurement, and several aspects of art. In studying the behavior of young children who were using electronic microscopes, Jones et al. (2003) found that one of the main effects was stimulating social interactions and the desire of students for linguistic expressions. Jones et al. (2003) noted that the microscope experience greatly advanced the students’ understandings of shape and scale, two key concepts in both art and science. Teacher A remarked on these same effects among the teacher’s art students. Teacher A found that it was important for students to look for art everywhere in nature, which was also a focus of the artistic body of work of Georgia O’Keeffe, for example, her 1920s-era paintings of flowers and shells (Benke, 2000).

Remarks group A-iv-P6 2 of 2. Teacher A stated the digital microscope enhanced the ability to meet state standards. The teacher found that digital microscopy “helped students to really understand the material better at a higher rate than previously instructed by the teacher.” Teacher A noted that the areas that benefited in particular were “art, science and social studies…art and science definitely … and reading … social studies;

we have found when they were studying money and they tied up the history, and if you were creative, it could be any of them [State Standards' subject areas]." In addition, Teacher A found that students were "better at identifying the different parts of a plant … looking at a flower what parts they are looking at rather than just 'oh look at this' they actually say 'oh, cool, that is the stamen' or 'oh, cool, that is the …', so they can use those terms again." The researcher noted how the teacher connected the digital microscope to state standards and also how the teacher mentioned other subject areas in connection with digital microscopy, including art, history, social studies, and science, especially biology (of the flower).

In teacher remarks about the digital microscope and *connection*, Teacher A spoke about how digital microscopy in art lessons helped students connect with other areas of the curriculum and with the biology of flowers in particular. Connecting other parts of the state curriculum to art lessons was not something new to Teacher A, but the way the connections were made in digital microscope lessons was new. This change, as Richardson (1990; 1991) pointed out, had to do with the teacher's background. The teacher wanted students to look closely at art objects and the digital microscope allowed them to do so.

Interview after first lesson 2004

Remarks group A-iv-A4 1 of 3. Teacher A stated that when students made their sketches from the digital microscope images of flowers and shells the "students [began] to fill the space like Georgia O'Keeffe would, all the way to the edges." The teacher added that "it helped students be able to really get what they were trying to get and it made them feel so successful rather than being challenged to just fill up the page." The researcher noted that this compared to the Georgia O'Keeffe method, except that it involved looking closely with the digital microscope, then taking the digital image, and finally making a sketch from the image, which was done later on in the art classroom.

In teacher remarks about the digital microscope and *connection*, Teacher A spoke about how the digital microscope allowed students to look closely at objects more like Georgia O'Keeffe did and to create large-sized drawings from the digital microscope images. Benke (2000) described Georgia O'Keeffe's art works as complete, large-size views of flowers and natural objects. Teacher A conveyed this to the students and found that the new technology achieved the goals that the teacher had of seeing the object and seeing it like Georgia O'Keeffe would.

Remarks group A-iv-A4 2 of 3. Teacher A stated that digital microscopes "show the students and teach them about light and dark and medium and getting those values in there to helps make it look three dimensional." The teacher found that "students take a picture of an object and save it and they are also the artist … because they are making the composition," and the students "experienced art" via the photograph of the digital microscope image. The teacher was excited about what happened and remarked "isn't this art neat…for second and third graders!?" The teacher stated that the students would "save the image and then make a quick sketch." The researcher noted that the teacher mentioned that digital microscopes were 'showing and teaching' the students about 'light and dark and medium' and the three-dimensional quality of art objects. The teacher explained how the students did their art lessons involving the digital microscope. The researcher noted that the teacher mentioned that the students 'experienced art' with the digital images. The students made the digital images in the computer laboratory and then returned to the art classroom to make sketches from the digital images.

In teacher remarks about the digital microscope and *connection*, Teacher A spoke about how students' initial work was in making digital images and then later in making sketches from the digital images. Jones et al. (2003) noted that students formed a haptic perception of objects by handling them and then by looking at them under the microscope. Teacher A also observed how the students handled the objects when using the digital microscope to view the magnified object. Although O'Keeffe did not use magnification, she had a viewing phase (Benke, 2000), which was similar to the haptic (handling) phase of the students using the digital microscope. O'Keeffe observed the object in fine detail and made her paintings from that observation. The students selected the digital microscope image that they wanted from their observation using magnification and then sketched or painted based on that image.

Remarks group A-iv-A4 3 of 3. Teacher A stated what "was neat about Georgia O'Keeffe's work is a lot of her paintings became very abstract … [she] enlarged them to make you look at [the image] in a whole different way." The students "[made] even a larger picture [by] looking at the image the students photographed with the digital microscope because Georgia O'Keeffe would tend to work really big." The researcher noted that the teacher made the connection between the 'really big' work of Georgia O'Keeffe and an 'even larger picture' by the students. In addition, Teacher A based her lesson on what the teacher gave as a quote from Georgia O'Keeffe's book: "When you hold a flower in your hand and observe it, you get lost in your own little world." The teacher noted that what O'Keeffe wanted in her art was for people just to 'get lost' in the painting. The researcher noted that this was what the teacher wanted the students to do. The teacher mentioned that it was important for "students to get lost in the images in their microscope." Teacher A noted that "Georgia O'Keeffe created art and this is art too … remember this is photography." The researcher noted the strong connection that Teacher A felt for the work of Georgia O'Keeffe and the teacher's planned lessons on this style of art. This was one of this teacher's key objectives, for students to get lost in the looking at the object using the digital microscope, in the connection to the artist, and in how this artist wanted the viewers of her art to get lost in the picture (just as this artist did while observing and painting the picture).

In teacher remarks about the digital microscope and *connection*, Teacher A spoke about how the digital microscope helped achieve the effect of 'getting lost in' the artistic image and achieving the artists' (Georgia O'Keeffe's) point of view. Benke (2000) noted that Georgia O'Keeffe's work was physically much larger than life in order to draw in the viewer and capture the viewer's attention. Teacher A asked students to try to achieve this and to 'look at the image in a whole different way.' As it was the goal of the teacher to change the view of students' perceptions of everyday objects, like flowers, the use of the digital microscope for this purpose was ideal (Jones et al., 2003).

Interview after lessons 2006

Remarks group A-iv-A6 1 of 3. Teacher A stated that the digital microscope "has definitely helped encourage them [teachers] to use it in their science [classes]." The teacher added that "I know that this year even more [teachers] have taken the time to set it up and use it and they have enjoyed it and the kids have enjoyed it." Teacher A stated that the art students used it to "study texture, which was tactile and visual so it was good to be able to look at yarn and then draw it.” The researcher noted that the teacher spoke first about science connections, but then addressed the connections within art such as texture and color. The researcher noted that Teacher A was confident in the statement that the digital microscope helped encourage students to use it in their science lessons. The researcher noted that Teacher A’s lesson was to study the texture of yarn because it was tactile and visual so it would be good to look at using the digital microscope and then draw it.

In addition, Teacher A planned to “continue with the study of the artist Georgia O’Keeffe.” Teacher A stated that students “discover textures … and I will just have to take the time and get it all set up so that it will happen.” Teacher A remarked that the teacher wanted to “look at fibers and maybe materials like crayons and pastels and really look at some of the tools we use everyday.” Teacher A’s reference that as a teacher ‘you have to make it happen’ was a reference to taking the time to allow it to happen. The ‘it’ was setting up a lesson that included allowing aside enough time to explore the texture in this case yarn and then draw what was seen. The teacher then addressed the fact that to make it happen the teacher must to set it up even though there was usually a fast pace that needs to be kept up with. The researcher noted that the teacher made a reference to time needed in exploration and discovery of texture, time needed to draw what was discovered, and time needed in planning this type of a lesson. The teacher noted that the lessons involving the Georgia O’Keeffe concepts would continue and would evolve. Teacher A wanted the student, by using the digital microscope, to understand how the artist interpreted nature. The teacher expressed that was important. The researcher noted the connection here was the art in the classroom, which the students were working with, to the art of the artist. Through this medium, this teacher connected to a variety of standards and objectives and then connected to nature or science. In addition, Teacher A mentioned that the teachers have taken the time to set up the microscope, which then was followed by student and teacher enjoyment. Teacher A stated that students discovered and looked at fibers to see texture and connect to other materials in art, like crayons and pastels. Also Teacher A wanted the students to ‘really look’ at some of these tools that we use in art every day. The researcher noted the connection to materials and that students should really look at them in their discovery of what makes the texture in yarn.

In teacher remarks about the digital microscope and *connection*, Teacher A spoke about how students discovered textures and details of everyday objects. As noted above, Jones et al. (2003) found that students form a *haptic perception* of objects (a Piagetian concept of student cognition) when they handled them and then looked at them under the microscope. In this instance, during the haptic phase, students discovered what some art materials like yarn looked like at a fine scale.

Remarks group A-iv-A6 2 of 3. Teacher A stated that digital microscopy “makes the kids excited about science.” Teacher A noted that digital microscopy in art lessons “opened their eyes so that it does not have to be used just in science.” Teacher A found that in using the digital microscope the teacher could “tie it in to social studies and they can tie it into art and many other areas and that is neat too.” Teacher A found that the students can “gain a lot of information not only in art but in science because they could see that detail and the colors and the shapes and the parts of the flower and all that goes with it.” The researcher noted that the teacher’s comments included the science-art connection and the connections with social studies as well.

In teacher remarks about the digital microscope and *connection*, Teacher A spoke about how the digital microscope helped connect art with science in the students' minds. As noted previously, Jones et al. (2003) reported that young students' perceptions were greatly changed by microscopy. Wright (2000) noted that students saw connections between art and science in graphic representations, such as the digital images made in the art lessons using digital microscopy. The combination of digital microscopy and making imagery of what they saw combined these two effects in one art lesson.

Remarks group A-iv-A6 3 of 3. Teacher A compared the digital microscope experience in art lessons to "how other artists interpreted nature and I think that is important because I could see that and I feel confident that [all the students saw this connection as well]." Teacher A mentioned that students "have a much better understanding of O'Keeffe and her style and how she looked at things and how it was very different than other artists." Teacher A stated that students "enjoy science in art more because I know that everybody is going to grasp the concept." In addition, Teacher A found that the students "are able to enjoy the art more because the students understand it … rather than having to fight through that 'no you don't quite get it, let's do it again' and the little frustrations … it helps them get over the hump and grow a little bit faster." The researcher noted that the teacher remarked again about interpreting nature through art, the Georgia O'Keeffe style, and the science-art connection. The word 'understand' that the teacher used above was important because this was a goal of the lesson. How an artist interprets nature could be very abstract and not easily achieved in a lesson but using the digital microscope this teacher was 'confident that all the students knew.' This teacher could observe and feel the confidence that the students had. The teacher discovered that the students understood how the artist interpreted nature by the connection from art in the classroom using the digital microscope, to the artist which in this lesson was Georgia O'Keeffe, to science, which showed the parts of the flower, and finally to understanding how the artist interpreted nature. The researcher also noted how challenging it was for this art teacher to provide a lesson that would enlighten the students about a concept, in this case, texture as seen through the eyes of an artist. The 'getting over the hump' as this teacher noted was a very defining statement and one that shows a physical side to an abstract process. One could actually picture someone or something going over a hump, for example, a hump in a road or even an event in life ('I finally got over that hump and now I can go on with things, etc.'). The portrayal of this concept and that the students could enjoy things now that it has been 'gotten over,' could also be pictured by anyone who also may have gone over an uncomfortable 'hump in the road,' in life's endless road to enjoyment and happiness, or in this case, enjoyment and understanding.

In teacher remarks about the digital microscope and *connection*, Teacher A spoke about how the digital microscope increased the students' understanding of how an artist like Georgia O'Keeffe interprets nature. In observing students doing artistic renderings of natural materials, Pestrong (1994) observed that these artistic efforts can hold and focus the attention of students on both the art and science qualities of the subject matter. Teacher A noted this effect in how the students could achieve seeing natural objects up close in both an artistic and a scientific way. This was especially pertinent because the intent of the artist (Georgia O'Keeffe) was to attract attention to the art object (e.g., a flower; Benke, 2000).

Category – Knowing

Pre-interview 2004

Teacher A made no coded comments in the category *knowing* during the pre-interview 2004.

Post-interview 2004

Remarks group A-v-P4 1 of 1. Teacher A mentioned how important it was to have exploratory time with the microscope saying that the students “needed time to understand before they were asked to do a specific lesson.” Teacher A went on to say that by “studying flowers and shells using digital microscopy students gained insight into ‘just seeing’.” This teacher also remarked that digital microscopy “gives students a little insight into how they can use science.” Teacher A found that students “could identify the [flower] parts although we didn’t label them as such they were very noticeable.” The teacher noted that students “document more about what they were seeing [with the digital microscope].” The researcher noted that the teacher felt that the students knew more because they were focused on ‘just seeing,’ which meant spending time actually looking at the objects in the art lessons. Because the students spent time ‘just seeing,’ they noticed parts of the flower. The researcher noted that students spent time documenting what they were seeing. In addition, Teacher A stated that digital microscopy “gave students just an idea ‘how to look’” and something to “write down some things and describe it.” The teacher found that digital microscopy also gave the students “just an idea how to document [their observations].” Teacher A described how digital microscopy “allowed them to get to see things that you don’t normally see and to be able to share that with somebody else you need to either write it down or draw it or do something to be able to share it with people or take a picture of it.” The researcher noted that these comments were important because drawing was very important to scientists and in becoming a scientist. The researcher also noted that students were learning how to document and describe what they saw and were sharing with others in a discourse. The researcher thought that it was unexpected for this teacher to include drawing, writing, and picture taking in comments about students as scientists.

In teacher remarks about the digital microscope and *knowing*, Teacher A spoke about the digital microscope helping students to learn how to see and then learning how to describe what they were seeing, which connected to students as scientists. Roth (1996b) described a significant transformation within an inquiry-based classroom when a new tool was introduced. According to Roth (1996b), the new tool promoted what he called knowledge diffusion and was important in stimulating the learning community. In a series of papers, Roth (1996a; 1999; 2003) described how the tool-related transformation included enriched student interaction (discourse and gestures) and artifacts (drawings and writings) that were part of the learning experienced by the student inquiry community. Roth (2003) noted that student interactions involved more verbal and written discourse using more specific language as students became more familiar with the phenomena they were studying. Roth (2003) noted how what he called scientific talk evolved in the classroom community and how students behaved more like scientists working in a laboratory as they became familiar with the tools and items being studied. Teacher A noted these effects and found them remarkable in these interview remarks. The teacher observed that the digital microscope (the *tool* in this instance) stimulated students to see and write in the ways the teacher had hoped before introduction of the digital microscope.

Post-interview 2006

Teacher A made no coded comments in the category *knowing* during the post-interview 2006.

Interview after first lesson 2004 and Interview after lessons 2006

Teacher A made no coded comments in the category *knowing* during the interview after first lesson 2004 and the interview after lessons 2006.

Category – Object

Pre-interview 2004

About the digital microscope and its relationship to specific objects, Teacher A anticipated that it would be useful to "look at flowers up close and maybe bones and some sea shells" and "to do the lesson with the flowers." In addition, Teacher A predicted that digital microscopy would be a way to "encourage the exploration of yarn, clay, and the texture of things that are in the art classroom." This teacher also expected that it will be a way to "study insects from the chrysalis on up and life cycle kinds of things." And, the teacher predicted that students will probably "look at their hand or face, if they realize they can take the microscope apart … because it is just right there … or their friend's face."

Researcher summary (object) from pre-interview. In remarks coded in the category *object*, Teacher A spoke about what the teacher expected that the students would see and do using the digital microscope. The teacher anticipated that art lessons might involve flowers and shells as art objects and that the class might look at art materials like yarn and clay. The teacher thought that students would like to see insects at stages in their life cycles as well as students' hands and faces.

Post-interview 2004

Remarks group A-vi-P4 1 of 1. Teacher A stated the "students looked at their hand, body, their eye, finger, and then their nose … [and the students] put their finger in it [under the microscope], but when they realized that it came out [digital microscope in hand-held mode], they went right to [looking at] their eyes or their nose."

In addition, Teacher A remarked that the digital microscope could be used in looking at "growing crystals" and Teacher A also noted that the digital microscope could be used to "look at parts of a flower." The researcher noted that as predicted by the teacher in the pre-interview, the students first looked at parts of their bodies as soon as they found out that the digital microscope could be taken off its stand and used in a hand-held mode. The teacher made comments about looking at growing crystals and parts of the flower. The researcher noted that the teacher described how the digital microscope could be used to look at parts of a flower instead of just looking at flowers which was what the teacher had anticipated that the students would observe.

In teacher remarks about the digital microscope and *object*, Teacher A spoke about what students tended to look at first using digital microscopy – themselves. Teacher A correctly predicted that the first thing the art students would look at would be themselves (faces, hands, etc.). Nakhleh and Samarapungavan (1999) studied beliefs among young children regarding the natural world. They noted that young students tend to think of objects in terms of themselves. Therefore, it was predictable that young students would look at some of their own features before moving on to other objects of interest.

Post-interview 2006

Remarks group A-vi-P6 1 of 1. Teacher A spoke about various things that the students had looked at using digital microscopy. The teacher stated that the students used digital microscopy to "look at money and all the things they could see on a dollar bill or on a coin." Teacher A also noted that the students used the digital microscope to "look at the flowers and at insects – the wings and the bodies." The teacher mentioned that the students "looked even at some dead flowers, dead wilted things and that was quite interesting." Teacher A found that the students "all the time bring in things they want to see – torn pieces of butterfly wings and stuff they want to see up under there because they know that it will let them see it, they can take a picture of it, and they can share it with other people." The teacher noted that the students could "see the plants up close" and then "study the plants."

In addition, Teacher A stated that digital microscopy could be used to "study a feather, or a rock, or a piece of wood, or whatever you could look at that under the microscope, [even] a coat or a button." And, Teacher A noted that the digital microscope could be used for other things "depending on how creative you are, it could be used [in almost] any area." The researcher noted that using the digital microscope enabled the students to become more interested in looking closely at things that interested each of them. The students became investigators as they took the picture of the object using the digital microscope, which then enabled them to share and discuss what they observed to other people. The researcher noted that the teacher allowed students to look at things they wanted to see, which represented a change from earlier lessons where the teacher gave the students things to observe.

In teacher remarks about the digital microscope and *object*, Teacher A spoke about the many things that could be viewed with digital microscope and the things that students wanted to see and brought in to observe. Jones et al. (2000) noted that it was important for students to have access to tools, but also important was the students' choice of what to do with the tools. In authentic scientific inquiry, Rahm et al. (2003) referred to the property of *emergence*, where something unexpected comes out of the inquiry. In the instance of authentic experience in an art classroom, it seemed likely that emergence could have arisen too, but this depended upon unexpected choices in art objects. This was where student choice came in, and Teacher A included student-driven choice in the lesson planning.

Interview after first lesson 2004

Remarks group A-vi-A4 1 of 1. Teacher A remarked about how students looked at "chalk up close and [how they] use different art materials … the clay, paper, [and] weaving." The researcher noted that the teacher spoke of some things that the teacher had anticipated that the students would look at such as yarn and clay, which were already in the art classroom.

In teacher remarks about the digital microscope and *object*, Teacher A spoke about examining art materials closely using the digital microscope. In studying young children, Nakhleh and Samarapungavan (1999) found that many do not have coherent notions about the underlying structure of most materials they come into contact with. For this reason, it was wise for Teacher A to encourage exploration of the art materials using the digital microscope.

Interview after lessons 2006

Remarks group A-vi-A6 1 of 1. Teacher A stated that the teacher "could gather materials that would be of interest to the students" so that they could really have a "better idea of what Georgia O'Keeffe had to work from." In addition, Teacher A noted that "insects were studied in second grade" and that the students were still fascinated by them. Teacher A related that there were many parts of the curriculum where digital microscopy could be used. The teacher found that "sometimes a classroom … might be studying insects for two weeks but the art teacher only sees the students two days out of the two weeks." Teacher A mentioned that there was a "time constraint [that affects the art] unit in the classroom." The researcher noted that the teacher found that it was important to prepare materials that would be of interest to the students. In preparing art lessons, the teacher stated it was also important to keep in mind what the artist being studied had to work from. This collection of things then had importance for students with regard to the ability to relate to the artist being studied. The researcher noted that the art teacher had a time constraint that was different from the regular classroom teacher. This was an added burden of time constraint that needed to be considered by the teacher when planning a lesson.

In teacher remarks about the digital microscope and *object*, Teacher A spoke about the teacher participating in the inquiry art lessons, students' prior knowledge and scaffolding of learning, and limitations on time for art lessons with digital microscopy. Bell et al. (2003) noted that teachers, who collaborated with students during inquiry as

Teacher A did, experienced positive effects of those inquiry lessons. Liem (1987) noted that teacher participation during inquiry lessons was essential for effective outcomes. Scaffolding on prior knowledge was a key element in student constructions of new understandings (Bouillion & Gomez, 2001). Roth (2003) included graphic representations made during inquiry as well as other forms of student discourse in the broader concept of scaffolding in student cognitive development from lessons within the inquiry classroom community. Teacher A recognized prior knowledge and student communications, including graphic representations, as being important in student lessons and used this effect in the teacher's new art lessons. Richardson (1991) recognized that time limitations were commonly related to teacher change, especially first-order teacher change where lesson planning was involved. Teacher A accepted the time limitations as part of the lesson's evolution, which indicates teacher willingness to change (Richardson, 1991).

Category – Seeing

Pre-interview 2004

About the digital microscope and its relationship to seeing, Teacher A anticipated "seeing" in different ways. One way that the teacher remarked about seeing was a belief regarding students and their "love to look at things up close." The teacher noted that the digital microscope "allows you to see things a little closer" and "to see what you cannot see with the naked eye." Also the teacher expected student interest in "seeing parts of the flower that they have not seen" and mentions that they would be able to "see colors and shapes and forms."

Researcher summary (seeing) from pre-interview. In remarks coded in the category *seeing*, Teacher A spoke about what the teacher expected that the students would see and do using the digital microscope. The teacher spoke about seeing in different way and that the students would love looking closely at things, perhaps seeing parts of a flower that they had not seen before.

Post-interview 2004

Remarks group A-vii-P4 1 of 1. Teacher A stated that "the students wanted to turn the item (flower, shell, etc.) around," "they wanted to look this way and that," and "they wanted to see all aspects of it." The teacher added that students were very intent on "observing … looking closely at things." The teacher found that students "enjoyed seeing parts of the flowers and shells that they were not able to see before." In addition, the teacher noted that we "use chalks and pastels or if we draw something and see what it looks like underneath – or fibers [if we are] looking closely at things in a different way." In this instance, the teacher was substituting a medium to try to capture the detail or texture of what was being seen. The researcher noted that Teacher A closely observed the students and remarked on how they handled the art objects. The teacher mentioned that the students liked to see small aspects of things (art objects) that they had not seen before.

In teacher remarks about the digital microscope and *seeing*, Teacher A spoke about students manipulating the art objects during their work with the digital microscope and their fascination with things not seen before in digital microscope views and images. As noted previously, Jones et al. (2003) reported that students achieved a Piagetian haptic perception of objects that they handled and then viewed microscopically. This haptic perception was viewed as very important in students' understanding of the physical properties of the objects examined microscopically (Jones et al., 2003). Roth (1996b) noted that physical manipulation of objects was part of the physical gesturing that he described among students who were engaged in inquiry within a learning community of the classroom. Jones et al. (2000; 2003) reported young students' fascination with the unseen microscopic world and the usefulness of this fascination in inquiry classroom learning. The literature examples cited here were about science classrooms, yet Teacher A also discovered these effects in an art classroom setting.

Post-interview 2006

Remarks group A-vii-P6 1 of 1. Teacher A stated that the students "looked at different materials and fibers, to explore textures … [and] looked at insects up close." The teacher noted that students "enjoyed looking deep inside the center of the flower or in the shell" and noted that they "turned the object over" while examining it. The teacher noted that the students "find the unusual … if there was some coral things stuck on … or a barnacle stuck on a shell … they thought it was cool … or if something had a hole in it they would look at that." The researcher noted that the teacher had a view of seeing during the pre-interview. After the introduction of the digital microscope, the teacher noticed student behavior as an indicator of how they were seeing according to their interests, the way they placed the objects, and their discourse in sharing their discoveries. The researcher noted that the teacher felt that the students were drawn to the unusual. The teacher noted that they would be interested in seeing parts that they had not seen and then would see colors, shapes, and forms. However, the teacher found that the students were intrigued with specific parts (the physical attributes) of art objects that were not observable before (what to them was the unusual). The students became intrigued by a new world of observing things that they discovered on their own and that fascinated them.

In teacher remarks about the digital microscope and *seeing*, Teacher A spoke about student exploration using digital microscopy and the students' fascination with the unusual. In reviewing constructivism in the classroom, Crowther (1997) noted that students learn by internalizing something new. The discovery of something unexpected at the microscopic level was something new to the students in this instance. Kusnick (2002) discussed young students' conceptual prisms through which they viewed the natural world and how those changed. One of the ways to suddenly change conceptions, as noted by Jones et al. (2003), would be to expose young students to microscopy. Teacher A noted that students were fascinated with the unusual, which represented in this instance a microscopic view of something unexpected and new.

Interview after first lesson 2004

Remarks group A-vii-A4 1 of 2. Teacher A stated that "students take the shells and flowers [two main art objects used by the artist Georgia O'Keeffe as] … a lot of her theme in her paintings, and picked their own view by studying these objects under the microscope." The researcher noted how this statement showed that the teacher found it important for the students to not only pick their own art objects (flower or shell) to observe but also to pick the view of the object and capture it as a digital image. The researcher noted that this was a new direction for this teacher. In previous lessons (without digital microscopy), students were given a shell or a flower to work with and, further, they were not able to save a digital image to work with later.

In teacher remarks about the digital microscope and *seeing*, Teacher A spoke about students working with the art objects using digital microscopy and also working with the images of the art objects made with the digital microscope. Roth and McGinn (1998) discussed the inquiry classroom, including the roles of student discourse and student-made inscriptions. In student discourse, the students used language, gestures, and body language to convey ideas about what they were finding to other students in the learning community. Teacher A described similar kinds of interactions among the students as they were manipulating objects during the digital microscopy part of the art lessons. Student-made inscriptions, which Roth and McGinn (1998) described as graphic representations of what students were seeing and doing, were used in another phase of inquiry. Similarly, Teacher A used the prints of digital images later on in the classroom setting as a basis for student activities in sketching, painting, and drawing. The study of Roth and McGinn (1998) was centered on an engineering activity, yet the similarities of what was described in this inquiry setting are remarkably similar to what Teacher A described in the art lessons. Teacher A described student decision-making about selecting objects for study and selecting images to work with later. This effect showed possible changes in the level of thinking skills among the art student group, who were at or near one of the Piagetian steps in thinking development (advancement to the level of being operational; Bosak, 1991; Phillips, 1994). In operational thinking, more reasoning and creativity emerge (Bosak, 1991), and this appeared to be happening with the art students as described by the teacher. Teacher A described specifically students selecting objects appropriate to the lesson, viewing the object as needed, imaging the object and then saving the image, and choosing an image and working with it to achieve set goals.

Remarks group A-vii-A4 2 of 2. Teacher A stated that digital microscopy "gives us a whole different level of looking closely at what you are drawing." The researcher noted that there was a discovery made by the teacher and the students that looking closely with the digital microscope represented seeing in a completely different way. In addition, Teacher A found that "we [teachers] say [to students] … observe, look … but now we get to show them [and] see it up close." The researcher noted that the digital microscope provided the teacher with a completely new way to 'observe and look closely.' In this way, the teacher discovered what the students did and said when they looked something more closely under magnification. In addition, Teacher A remarked that the teacher and students "discovered that the camera [in the digital microscope] picks up more than what your eyes can see … [it] definitely picks it up in a more confined way." The researcher noted that the teacher spoke about the digital microscope versus the eye. In so doing, the teacher addressed a technical point with an artist's perspective. The teacher had observed something that the digital microscope did that was better than the eye 'because the digital microscope picked up details that the eye did not.' The researcher also noted a deeper analogy here between the digital microscope seeing more than the eye and the way that an artist sees more deeply into the hidden meaning of things.

In teacher remarks about the digital microscope and *seeing*, Teacher A spoke about students seeing on a 'different level' with the digital microscope and how differently the digital microscope 'sees' versus the eye. As noted previously, Jones et al. (2003) discussed the different perception of the world young students possessed after having worked with high-magnification microscopy. As a collaborator with the students, Teacher A's perspectives were changed as well (Bell et al., 2003; Liem, 1987).

Interview after lessons 2006

Remarks group A-vii-A6 1 of 2. Teacher A stated that in order to "see more detail and to have more variety … we had a basket full of different sea shells." Teacher A found that the activity allowed students to "see more clearly what Georgia O'Keeffe could see on her own" and that "she could – in a way – she had her own microscope-kind-of-eyes … [so that] when she looked at a flower or shell she saw what the kids are seeing with the [digital] microscope." The researcher noted that this built on the teacher's earlier observation about the digital microscope's camera 'picking up more than what your eyes can see.' In addition, Teacher A mentioned that with the digital microscope you "see things that I could not see and they [the students] could not see because of the [digital] microscope." Teacher A also commented that students "see deeper, deeper into the parts of the flower, deeper into the structure and how it was made." The researcher noted that the teacher related being able to 'see deeper' to the lesson on the artist Georgia O'Keeffe. The digital microscope enabled students to see the deeper structure of the shell or flower and therefore gain insights into how the objects were made. The researcher noted that this comparison and how the students connected to an artist by using an instrument to 'see like the artist' suggested that Teacher A realized how this digital microscope enabled this teacher to see what the students observed. This helped students to understand a concept that had been difficult to convey in the past.

In teacher remarks about the digital microscope and *seeing*, Teacher A spoke about the comparison between the artist's eye (in this instance, Georgia O'Keeffe's eye) and the digital microscope's view of art objects. Benke (2000) noted that it was the stated goal of O'Keeffe's work with flowers and shells that the viewer would be drawn into the paintings, which depicted flowers and shells at huge size. O'Keeffe wanted viewers to think about the art objects and see more deeply into their nature and origin. Wright (2000) pointed out that a strong connection of art and science is that in their graphic depictions both artistic and scientific renderings convey information as well as deeper meanings about structure and origin. Teacher A wanted students to see deeply and look for this duality of meaning through the process of looking closely at art objects. Teacher A chose similar art objects as O'Keeffe – flowers and shells.

Remarks group A-vii-A6 2 of 2. The teacher stated that the ability of the students to "pick their own shell or flower" and then to "pick the image that they found to be the most interesting" again revealed a keen interest by the students who have been driven by their own motivation to "see what was of interest to them." Teacher A noted that to "study the structure [of flowers] they could look at shape and color and it sort of gave them a jump start." The teacher mentioned also that the "same thing [happened] with the shells, and they were so fascinated … [saying] 'oh, cool'… [and] they would turn it over or see the textures that they could not see with their naked eyes." The researcher noted that the teacher described what students did was important to observe. The researcher also noted that it was important for students to choose for themselves what they wanted to work with in the art lessons.

In teacher remarks about the digital microscope and *seeing*, Teacher A spoke about students choosing what they want to observe and the teacher's participating with them. Krajcik et al. (1998) studied project-based inquiry lessons where the teacher designed the lessons and then participated with students. Bell et al. (2003) found that similar collaborative projects like this worked well and had positive results for teacher and students. Liem (1987) noted that teacher participation during inquiry lessons was essential for effective outcomes. Students choosing for themselves what they want to observe and how they want to observe them was part of the inquiry process that helped drive student inquiry (Roth, 1997). Teacher A found this was an effective strategy in the art lessons described here.

Category – Students

Pre-interview 2004

About the digital microscope and students, Teacher A anticipated that digital microscopy would be a way for students "to explore," "do paintings," and "be very scientific." The teacher added that digital microscopy would be a way "for students to want to touch the digital microscope" and "for students to want to use the digital microscope even though they did not know exactly what it did." In addition, the teacher predicted that digital microscopy would be a way "for students to see things in their own head" and "for students to use their imagination and then get it on canvass."

The teacher went on to say that digital microscopy would be a way to "get them to express their feelings by looking at an object and then writing about it" and to "scientifically record observations [of] what the students saw." The teacher noted that digital microscopy would be a way "for students to want more of whatever it is that the teachers are allowing them to [do]," and "for students [to use] their imaginations and their just natural curiosity is just going to go bananas." Also, the teacher mentioned that digital microscopy will be a way "for students [to learn a lot] especially because that is what elementary is… students are just like sponges." Teacher A anticipated digital microscopy will be a way for students "to be very curious and gain so much information and data that they are going to process" and "to find [that they] are just going to want to explore everything." The teacher found that digital microscopy would be a way to "encourage … different grade levels to look at objects up close."

And, the teacher expected that "younger students are going to be just so open to soak in whatever the teachers are going to allow them to have the opportunity to explore." And, the teacher added that the digital microscopy experience will be a way "for students to ask lots of questions" and "for students wanting to know what does the digital microscope do." The teacher commented that "everybody will want a turn, so it is really nice that we have enough to meet the needs because it would be frustrating to just have one but it would be great but frustrating because everyone wanting to have a turn." The teacher also predicted that "students will draw after using the microscope when the teacher gets them to draw something in art something that stands for scientists they will draw these beakers or test tubes and stuff like that but this teacher mentioned that probably now they will draw a microscope after this." And, the teacher expressed that digital microscopy "gives the students a little prestige" because "the students associate a microscope with science." The teacher added that "students have a good time seeing … tools and supplies that we use all the time" and "students have a great time looking at our chalk pastels and our paint." And, the teacher predicted that "students will have a lot of fun just exploring what is in our environment that we work in every day" and that students will "have so much more information to pick and choose from."

Researcher summary (students) from pre-interview. In remarks coded in the category *students*, Teacher A spoke about what the teacher expected that the students would see and do using the digital microscope. The teacher mentioned exploring, seeing, imagining, and doing paintings. The teacher also spoke about getting them to express their feelings, record observations, work on lessons, become excited and use their imaginations, be curious, and soak up information. And, the teacher mentioned asking a lot of questions, everyone will want a turn to use it, drawing and working on art activities, feeling like a scientist, having some prestige, and having a lot of fun doing the lessons.

Post-interview 2004

Remarks group A-viii-P4 1 of 1. Teacher A stated that digital microscopy tended to make "students want to use it again and they want to incorporate it into their work" and "the students were just amazed at what they were seeing." This teacher also remarked that the "students figured out that [digital microscopy] was pretty cool." In addition, the teacher added that "in art, the students just thought it was really neat playing with the combinations of flowers and shells and zooming in … [at] different angles." This teacher found that "students realized that these images in art and science are pretty cool." Also, the teacher noted that students "point to things" and were commonly "working as a whole group." The researcher noted that the teacher described the amazement of students at what they were seeing, especially the flowers and shells. The teacher mentioned 'images in art and science,' which indicated a connection in the teacher's mind that was likely conveyed to the students. The researcher noted that the teacher mentioned students wanting to 'work as a whole group.' This was a change from the usual pairing of students in the computer laboratory where the part of the art lessons where the digital microscope was used take place. The researcher also noted that the teacher mentioned students 'pointing' as well as talking. This related to research about gesturing as part of discourse.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about students working in a group where they were discussing what they were finding and ‘pointing to things.’ Roth (1994) found that students communicated their findings in an inquiry-based classroom in a way much like researchers would do as a group working in a laboratory. Roth stated that hands, eyes, and signs were used by students to communicate. Roth noted that students used inscriptions, which he broadly defined as visual representations that stimulated discussion in the absence of good understanding. Roth particularly noted gesturing and pointing as indicative of student discourse where language and terminology was not developed in order to fully convey what was being discovered by the students. Teacher A mentioned the interaction (‘working in groups’) and gesturing (‘pointing to things’), which was very much like what Roth described.

Post-interview 2006

Remarks group A-viii-P6 1 of 5. Teacher A stated that digital microscopy “freed up the student” and that students were “able to manipulate and make choices rather than just view [what the teacher said to look at].” The researcher noted that the teacher found that students made their own choices. This was a more specific observation than what the teacher anticipated in the pre-interview. Also, the teacher discovered that “the students have so much more information to pick and choose from.” The teacher was more specific than before on how the students could do this and these statements revealed more about how students in this instance learned on their own and through their own discovery. The teacher revealed this to the researcher by making comments about students’ ability to manipulate and choose an object to be studied. This teacher also found that students using digital microscopy “gained a greater understanding of the artist … Georgia O’Keeffe,” and that the students “gained a greater understanding of (the digital) microscope and a greater understanding of science and how neat it can be.” The researcher noted that the students were seeing like Georgia O’Keeffe saw with her eyes but the students saw in a similar way by using the digital microscope.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about students freely choosing the objects that they wanted to look at during the digital microscope art lesson on Georgia O’Keeffe. Roth (1999) discussed the central role of focal artifacts in the social environment of a classroom community. According to Roth (1999) focal artifacts, which were things to look at and study, provided a forum for conversation in the classroom community and students developed a shared discourse based on looking at and studying the focal artifacts. In this instance, the teacher noted that the students selected their own art objects (focal artifacts) and their choices helped them become part of the art classroom community.

Remarks group A-viii-P6 2 of 5. Teacher A mentioned that students could see “how maybe a scientist even could get exited about looking at a crystal growing or something … and then just devoting their whole career to one little part.” Also, the teacher found that the students “gained a greater understanding of the microscope and a greater understanding of science and how neat it can be … and how maybe a scientist could get excited about looking at a crystal grow … and just devoting their whole career to one little [thing].” The researcher noted that the teacher found, by being excited themselves, students could relate to how others could be excited about similar things. The students were able to relate their level of interest through feelings and learn how a scientist might feel. The teacher related this to the researcher by commenting on the excitement, which the teacher observed that the students had while observing objects under the digital microscope.

In addition, this teacher noted that with digital microscopy the students "have had a little glimpse of how somebody could really [be immersed in research], whereas before [digital microscopy] they did not quite get it." The teacher remarked that "students found it fascinating because they could not see that with their naked eye." The researcher noted that the teacher mentioned a change in the students' reactions that the teacher observed from previous lessons. The teacher now saw a change in how the students can 'get it,' where 'it' means a greater understanding of the microscope and science. The teacher found that the students were fascinated 'because they could not see it with their naked eye.'

In teacher remarks about the digital microscope and *students*, Teacher A spoke about how the digital microscope evoked feelings from the students, particularly about gaining insight, having the desire to study something in detail, being fascinated with what was observed, and the 'aha moment.' Herrenkohl and Guerra (1998) and Pearce (1999) noted that if students were given time for metacognitive reflection they would think more scientifically and would be better able to process what they observed. This might include the development of attitudes and feelings about research, scientists, etc. (Carlson, 2001). Costa (2001) wrote about the 'aha moment,' explaining that students reflected on what they had seen and the processes by which they saw those things and as a result made deeper cognitive connections. Therefore, the so-called 'aha moment' was part of metacognition (Donovan et al., 1998; Herrenkohl & Guerra, 1998; Pearce, 1999; White & Frederikson, 1999), and represented an uncommon metacognitive jump. Teacher A noted the students' change in feelings and thoughts after they had time to think about what they were doing and seeing and remarked on this, including the 'aha' feeling in these remarks.

Remarks group A-viii-P6 3 of 5. Teacher A found that students could "hold and draw [objects]," "so it was a good activity, but I really just think that component [of being able to see objects] on that big screen is the thing that, [with] elementary in particular, helped them [versus using the magnifying glass in the past]." The teacher found that the students were able to more effectively do their art lessons versus the old way (the magnifying glass) of the past. The researcher noted that the teacher revealed that 'seeing it on the big screen,' whether the desktop monitor or the big screen in the front of the room, helped the students understand and depict objects in their art lessons. The researcher noted that whereas the object was magnified, it was the image that was captured and stayed the same for the students to study later on.

In addition, the teacher stated "how funny it is when they realize that they can turn up the power" and that digital microscopy "allowed them a lot more freedom and … artistic license." The teacher added that the lessons on digital microscopy "needed just that whole period just to play with the microscope and get to use it … because they were so excited about it." The researcher noted that the students' reaction to 'higher power' showed increased interest in magnification. The researcher also noted that free exploration and excitement were significant. When students were excited, it was good to let them explore with lesser time constraint. The teacher revealed how students learned: having more freedom and more time, having less time constraints, seeing the activity as play, having the ability to control the lesson and having artistic license, and possessing the key to it all – excitement about what they were observing. This goes back to the curiosity that drives learning, which was mentioned in the pre-interview, and was actually observed and described using the digital microscope lesson. The researcher noted that the teacher found that curiosity among students promoted acquisition of information to process.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about the value of having students ‘hold and draw’ the art objects and also saw them with the digital microscope on the ‘big screen’ (meaning the computer monitor or the screen in the front of the room). Regarding the ‘hold and draw’ component of the lessons, Jones et al. (2003) found that students gained a Piagetian sense of haptic perception when they handled objects and then saw them under magnification. By haptic perception, they meant gaining an understanding through touch as well as magnified vision of the physical properties of objects. Regarding the large-scale seeing of magnified objects, Roth (1994) and Roth and McGinn (1998) addressed this topic, referring to what they called inscriptions. As noted previously, inscriptions were visual representations of objects that the students could share in discourse and interaction. In this instance, the inscriptions were computer-monitor or big-screen displays of microscopic views of the various art objects that the students were observing. By using these large-scale inscriptions, the teacher and students were simultaneously engaged in discovery and discourse.

Remarks group A-viii-P6 4 of 5. Teacher A found that students would tend to “share it (digital microscopy) more with other people” and that the digital microscope “helps with their insight.” The teacher also stated that digital microscopy was a way to “gain insight … I think by observation, isn’t it?” Lastly, the teacher remarked that “just by watching them and listening to them” a teacher gained insight into student inquiry.

The researcher noted that the teacher found the importance for students to have discourse and interaction during inquiry lessons. The students could share what they were seeing and could share their findings with other students, which helped with their insight and the students gained insight by the observations of others and student interactions. The researcher noted that at the same time, the teacher gained insight by watching and listening to student interactions with each other. The result was two fold, in this case, and showed how the teacher was able to find out how students learned from each other. This led to the realization that the actual interaction between the students was also a learning experience and amplified learning in a different way. What the students observed through their own curiosity was then shared with other students, who verbalized what they were actually feeling as well as seeing. The gestures and the other students' responses became part of the shared inquiry that was not anticipated by the teacher. The teacher also became aware and learned not only according to what the students put on the screen (to be observed by others), but also by what the students felt and the 'why' behind the object's being magnified. The actual interplay of gestures and words may have been far more beneficial to both the teacher and the students than just verbal discourse.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about students sharing and gaining insights while using the digital microscope as the teacher participated as an observer and leader of the lesson. Roth (1994; 1999; 2001a; 2003) and Roth and McGinn (1998) found that students in an inquiry-based classroom needed to interact (have discourse and use gestures and body language) in order to convey their findings while developing understandings and more stable language regarding what they were seeing. Teacher A noted that 'sharing' led to their 'insight,' as pointed out by the Roth studies and other researchers. Liem's (1987) widely followed view of inquiry included the teacher as participant and leader (more like a guide) of effective inquiry lessons. Teacher A followed this course of teacher as participant (guide) and achieved the goal of the lessons as a result.

Remarks group A-viii-P6 5 of 5. Teacher A stated that students "get so engrossed in what they are doing they might forget their source … but definitely the source put them to that point and then you have to … be able to bring them back to remember – where did you get that information." The researcher noted that the teacher found students could become engrossed in what they were looking at and needed a point to come back to so they would know where they were at the beginning and where it led them. Also, the teacher found that students "interact with [the digital] microscope and whatever you have given them to look at … I just think by observation mostly, and by listening." And, the teacher commented that the digital microscope will "make the flower get bigger and [then] it becomes sort of abstract [to them]." The researcher noted that the interaction of technology of microscopy and object of interest promoted dialogue and also visual clues into what students saw and found interesting. The teacher remarked that magnification 'makes the flower get bigger' and then – to the students – it becomes 'sort of abstract.' In this instance, the teacher learned another dimension of the digital microscope and how it could help with art lessons, especially the abstract part of the lesson (i.e., using the artist Georgia O'Keeffe's style of art). The researcher noted that technology and the ability to magnify related art objects in the art lesson to the style of the artist Georgia O'Keeffe.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about students learning by observing and listening during the art lesson with digital microscopy. As noted above, Roth (1994; 1999; 2001a; 2003) and Roth and McGinn (1998) found that students in an inquiry-based classroom interact (have discourse and use gestures and body language) in order to convey their findings. This was necessary because of the social environment of the classroom and the absence of a more stable language to describe what they were seeing. Teacher A found that students have to think (be ‘engrossed’), look (‘observe’), and discuss (or ‘listen’) in order to learn in this community setting.

Interview after lesson 2004

Remarks group A-viii-A4 1 of 6. Teacher A stated that “students wanted to show form.” The teacher went on to say that digital microscopy was a way to get students “so excited” and keep them “experimenting.” The teacher recalled that “a couple of the students … [who] were looking at [the digital microscope] and their partner … went to get a shell and they came back and they [said] ‘oh neat!’” The teacher went on to say that “it was like they were seeing something that they had not seen [before] because their friend had maybe scooted it over and showed just an enlarged part [previously hidden] and…it was real fun.” The researcher noted that the teacher was able to observe the students’ enthusiasm through interaction and discourse between students. An example of the discourse noted by the teacher was ‘oh neat’ and an example of interaction was ‘scooting over to share what they discovered.’ The researcher noted that the students were ‘seeing something that they had not seen’ – as stated by the teacher – which showed that the students were learning from each other at the same time, they were using the digital microscope. In this process, the researcher noted, the computer monitor became a tool of communication for sharing discoveries. The students were able to share not only their own discoveries but also participate in what other students were discovering. They learned to show an enlarged part of a shell instead of the whole object through interaction with other students. The researcher noted that had it not been for the interaction between students, the way the room was arranged to permit this interaction, the ability for students to freely share with each other, and the safeness of the learning environment, the reported discovery and learning from each other might not have occurred as it did in this art lesson.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about the importance of students sharing with each other during art lessons with digital microscopy. As noted above, Roth (1994; 1999; 2001a; 2003) and Roth and McGinn (1998) found that students in an inquiry-based classroom need to interact (have discourse and use gestures and body language) in order to convey their findings. Interaction (sharing) was essential because the classroom functioned like a learning community where student discourse led to discovery and learning. Teacher A remarked on this before and came back to this observation once again here.

Remarks group A-viii-A4 2 of 6. Teacher A found that students liked "taking that part of the microscope loose so that they could control it differently." The teacher added that students "use shape and color and texture … [for example to] see this daisy kind of picture … the corner of it is just part of the flower." The teacher stated that digital microscopy was a way to "use the elements of art that the students want to focus on." The teacher remarked that with digital microscopy students were "able to see the texture and…look at this shape…be able to think about all this" and students are able to "help each other and line it up and try to see in a whole different realm." The researcher noted that the students were allowed to discover the hand-held mode (‘taking it loose’) during exploration on their own. This discovery and its application showed that students freely wanted to try different things on their own without the instruction of the teacher. The researcher noted that the digital microscope helped the students to see texture, as the students looked more closely at art objects. Because the students were able to freely explore and observe objects like flowers under different magnifications, lighting, as well as different angles, the students were able to capture a small part of a flower and study it. Then, they used shape, color, and texture to capture the image in their own sketch of the object observed. The image that they captured (and then used in creating their own art) involved just a part of the flower that they were observing closely. The researcher noted that the teacher found that the students used the elements of art that the students ‘wanted to focus on,’ which represented a change from previous statements. The researcher noted that the teacher observed that student interaction helped the students see in a different way and also the teacher mentioned the interactions between students as they helped each other ‘line it up,’ which provided an opportunity for students ‘to see in a whole different realm.’

In teacher remarks about the digital microscope and *students*, Teacher A spoke about students focusing on what they wanted to see and how students helped each other with the digital microscope art lessons. As noted above, Roth (1994; 1999; 2001a; 2003) and Roth and McGinn (1998) found that students in an inquiry-based classroom must interact (have discourse, etc.) in order to convey their findings. Interaction (helping each other) was essential in this setting (Liem, 1987), because the classroom functioned like a learning community where student discourse led to discovery and learning. Teacher A used the terms ‘think about this’ and ‘helping each other’ to describe some of the student discourse and interactions going on in the art classroom.

Remarks group A-viii-A4 3 of 6. Teacher A stated that the digital microscope allowed the student “see the texture … and look at shape … and then think about this.” The researcher noted that the teacher not only observed that the students were able to see the texture that the teacher had been trying to instruct the students how to draw, but the students also could think about this and apply what they learned to another shape as well. This mention of cognition on the part of the student to **‘**think about this’ was a leap by the teacher to, not just instruct about texture, but to allow the students the ‘time to think’ about what they were observing in regard to texture. The researcher noted that shape and color did not seem as abstract as the texture of the object observed. The digital microscope helped in this leap to a concept that had not been easily taught in previous lessons without the digital microscope.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about students needing time to think about the digital microscope lessons, which related to a larger concept of holistic learning. As noted previously, Herrenkohl and Guerra (1998) and Pearce (1999) noted that if students were given time for metacognitive reflection they would think more scientifically and would be better able to process what they observed. Carlson (2001) noted that this time for reflection enhanced student insight in areas similar to the present instance where students reflected on shape and texture of art objects seen with the digital microscope. Teacher A noted that this ‘time to think’ was an essential part of the lesson. In addition, the teacher described a type of holistic learning that is based in the Piagetian concept of operational thinking, or thinking that makes logical connections among disparate subjects (Bosak, 1991).

Remarks group A-viii-A4 4 of 6. Teacher A stated that students “took advantage of the microscope coming apart by combining a shell and a flower together.” The teacher noted that the students “turn it to the 10, to the 200, and the 60, and then they could experiment with that.” The teacher recalled that “a [young male student] said that he could watch it on the screen … and so] we can see … what they are doing.” Teacher A found that digital microscopy made students “want to be at their microscope … be observant to the other monitors … [do things that would] catch your eye.” The researcher noted that the students took advantage of the digital microscope’s ability to view objects in a hand-held mode that were too large to be placed under the microscope on its stand. The students were able to observe combinations of shells and flowers that were previously not possible to view at the same time. The students then were able to look at combinations of objects and this offered opportunities of different artistic combinations. Regarding turning up the ‘power’ of the digital microscope, the researcher noted that the teacher allowed the students to experiment with different magnifications on their own. The researcher noted that the teacher could observe the computer screens and in this instance saw what the students were interested in seeing. The researcher noted that even while the students were busy observing their own work, the teacher observed that they were very cognizant of the other students’ monitors. The researcher noted that the teacher was able to find out through observation of the students that the interaction between the students included more subtle interactions that could easily go unnoticed (for example, gestures). The students not only interacted with each other to share in their own unique discoveries but also checked what the other students were doing along the way. The benefits of the social aspect of using the digital microscope should be expanded to include non-dialogue gestures and eye and visual connections.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about the social aspect of students' interactions during activities using digital microscopy including 'keeping an eye on what other students are doing.' As noted previously, Roth (1994) found that students communicated their findings in an inquiry-based classroom much like a group of scientists working in a laboratory. Roth (1994) noted that hands, eyes, and signs are used by students to communicate. Teacher A's comments here also relate to students' visual communication – the teacher mentioned 'watching on the screen' and 'keeping an eye on what other students are doing.'

Remarks group A-viii-A4 5 of 6. Teacher A stated that digital microscopy was a way to "use more science kind of words to describe what the students see" and "have everybody else see it … on the student's computer [monitor] and they would capture it on a digital picture." The teacher found that students could "capture exactly what the students wanted to show, what they were seeing" and that this allowed students to "look closely" and "in a new way." The teacher remarked that digital microscopy "allowed students to see an object like they have never seen it … [and] build onto what the microscope is showing you." The researcher noted that the students were given the freedom to explore on their own and then selected the image that they wanted to share. This ability to capture what they wanted helped in their ability to show not only the other students but the teacher as well. This allowed all to see what each was seeing. The researcher noted that the teacher did not differentiate between which part of the lesson was science and which was art. Interconnection of art and science seemed to flow out of the lesson and the two were intertwined and became a more holistic learning experience for the students and for the teacher. This was a change from previous statements where the teacher was focusing on the science and the art as separate as well as writing and history. The change was that this lesson using the digital microscope in art became a bridge to science and back again to art.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about emerging scientific language used by students to describe what they were seeing using the digital microscope and the interconnection of art and science emerging in the art lessons. Roth (1994; 2001a) discussed the emergence of discourse using more scientific terms as a consequence of continued activity in the inquiry classroom. Roth (1996b) called this a transition from newcomers to old-timers, which only comes with time spent doing inquiry. As noted previously, Roth (1994) found that students communicated their findings in an inquiry-based classroom much like a group of scientists working in a laboratory. Scientists in the laboratory learned and evolved in a similar way, leading to enhanced communication, which Roth (1994) called scientific talk. The students' vocabulary changed enough over the first year of use that Teacher A remarked on the change during this interview. The implicit connection of art and science in a microscopic view has been shown beautifully in works by Davidson and Lotus (1993) and Dabdoub (2003).

Remarks group A-viii-A4 6 of 6. Teacher A found that digital microscopy was a way to "be so into what they were doing" that students "have a high level of interest for everyone, both boys and girls." The teacher added that "students did not want to quit! …

[all] students wanted to finish this drawing segment [and did not want to leave the class].” The teacher stated that “students just wanted to start looking” using the digital microscopes and “made their digital picture and then started a drawing of it.” The researcher noted that the teacher was impressed by this keen interest on the part of the students. The researcher noted that the teacher was observing the students for differences in interest by gender and there did not seem to be a difference in the high level of interest. About the students ‘not wanting to quit,’ the researcher noted that the teacher observed how the students were all very interested in what they were doing, both boys and girls, and the students did not want to stop and were eager to look at the objects. Then, this interest carried over into the art component where after they took the digital picture they wanted to start drawing it. The researcher noted that this interest tied the digital microscope firmly to the science of observation of things found in nature, in this case shells and flowers. Then, by taking a digital picture, the observations that the students were so keenly interested in were preserved and could be used later on in drawings that the students made in the classroom.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about students having a high level of interest, regardless of gender. Seiler et al. (2001) showed that high levels of interest in classroom activities could be achieved by using technological tools that engaged the students in inquiry. They noted that the students responded best to technology that allowed discovery of new things and learning about the technology. They noted that this worked well in diverse classrooms where students had a social opportunity to earn the respect of others.

Interview after lessons 2006

Remarks group A-viii-A6 1 of 5. Teacher A stated that in the past “students were willing to work in groups … because initially we teachers had them in pairs in the lab, like the first year that the program was implemented.” The teacher found that “everybody could have their own materials and work at their own rate … but they still (they continually) wanted to call people over to see what they discovered.” The teacher remarked that “they do like to share!” and “I think it did show me that everybody was engaged.” The teacher added that “there were no students [who said to me] ‘I don’t want to do this’” and “everybody wanted to participate.” The researcher noted that the students first worked in pairs, but wanted to work in groups and expressed this to the teacher. The teacher found that students worked better as a group according to the actions and statements of the students. The researcher noted that the teacher called attention to the fact that it was important for each student to have their own materials, and it was also important for students to work at their own rate. Regarding the students’ statements to the teacher, which the teacher summarized by saying ‘they do like to share,’ the researcher noted that this connected to research emphasizing the importance of discourse and gesturing among students in a learning community. The teacher observed that no one was left out and everyone wanted to participate.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about the desire of the students to work in a group rather than in pairs and that everyone was engaged in what they were doing with the digital microscope. As noted previously, Roth (1994) found that students communicated their findings in an inquiry-based classroom much as a group of scientists communicated while working in a laboratory.

Roth found that the social aspects of learning were of special importance during inquiry. Teacher A's comments here, as they have previously, showed the students desire to work as a group, whether the teacher wanted to pair them or not, which was similar to the findings of Roth (1994).

Remarks group A-viii-A6 2 of 5. Teacher A noted that "students [originally] worked in pairs … and they did well" but "they all wanted a turn!" so it became more of a group activity. The teacher found that "you know one would do the flower and then one would do the shell, and they would change [art objects]." The teacher added that "[we teachers] will use it [the lesson] again … I think just on our level [K-5] we are at such a fast pace it doesn't always allow us to do everything we want to do." The teacher was "glad that we are using it" and that the teacher and students "think it is great." The researcher noted that what the teacher learned was that the students did not want to be passive participants and liked to work in a group. They wanted their turn in each part. They each wanted to select and observe their own shell and flower. They wanted ownership in the process of selection of the object as well as the opportunity to manipulate the microscope, focus and observe the object, and then take the photo of the image that they wanted. They were interested in sharing what they selected with the other students and then comparing it to what others discovered and then they wanted to try it on their own after seeing what the other students found. The researcher noted that the teacher learned how it was important for each student to have the opportunity to control his own learning even when the lesson was set up as working in pairs. About the teacher's comments on time constraints, the researcher noted the teacher's awareness that time was a factor in a lesson such as this.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about the students desire to work as a group, and that each students would have his or her own turn. As noted previously, Roth (1994) found that students communicated their findings in an inquiry-based classroom much as a group of scientists communicated while working in a laboratory. Roth found that the social aspects of learning were of special importance during inquiry and therefore students tended to work as a group. Teacher A's comments here, as they have previously, also showed the students desired to work as a group.

Remarks group A-viii-A6 3 of 5. Teacher A found that digital microscopy "enhanced their ability to relate and connect with the artist [Georgia O'Keeffe]" and "helped them look a little more closely [at objects]." The teacher added that "students saw even more … I mean their little young eyes can see pretty well compared to my eyes." And the teacher remarked that digital microscopy was "a whole discovery process." The teacher added "this is what I liked." The teacher added that "I think it could have been money, I think it could have been a grain of sand, it could have been anything that they were looking at, but it was the whole process of 'wow, wow look' or 'hey – look at what I found!'" The researcher noted that the teacher was enthusiastic and related back to the objective of the lesson that was for the students to connect with the artist. The teacher wanted the student to learn to observe and then draw what they found interesting and in this way would connect with the artist and how the artist may have observed and drawn an object. Regarding the teacher's statement about the 'discovery process,' the researcher noted that the teacher connected the discovery process to the 'wow factor' and the 'sharing with other students their enthusiasm about what they found.' The researcher noted that this was an important statement by the teacher and revealed what the teacher believed the discovery process to be.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about some specific utterances from the students such as ‘wow, look’ and ‘hey, look at what I found,’ which were invitations for other students to engage in the discovery process. As noted previously, Roth (1994) found that students communicated their findings in an inquiry-based classroom much as a group of scientists communicated while working in a laboratory. Roth et al. (1999) found specific student utterances were not so much properties of the individual students as they were signals to the classroom community. In this instance, the signals likely were given to alert other students to discoveries that should be viewed and assimilated by the group. Teacher A’s remarks included these specific remarkable quotes from students as they worked as a community group.

Remarks group A-viii-A6 4 of 5. Teacher A noted that digital microscopy was still a way to “have a discovery kind of process when they were actually using the microscope.” The teacher added that “the students have changed since the beginning of the program [referring to 2004] because digital microscopy is not brand new anymore.” The teacher also found that “with the enrichment teacher using it and sometimes [other classroom teachers] using it, the students are much more familiar with the [digital] microscope, therefore they know how to manipulate it, they know what to expect, they know how to make movies, they know how to use all the features that are on there.” The researcher noted that the digital microscope and the lessons that the teacher used, continued to create an environment that promoted the discovery process. The change noted here was that the students of 2006 were more aware of digital microscopy than students were two years earlier so the experience, while still fascinating, was ‘not brand new anymore.’

In teacher remarks about the digital microscope and *students*, Teacher A spoke about how the students had changed over the time since the digital microscopes were first introduced at the teacher’s school saying that they all came to art class now knowing how to use the equipment and what it could do. Studies by Herrenkohl and Guerra (1998), Krajcik et al. (1998), and Pearce (1999) showed positive benefits and changes in students over long-term exposure to project-based inquiry organized around a central theme or tool. In particular, they pointed to the improved metacognitive abilities of students who were experienced in the inquiry-based methods. Teacher A noted that the student were still impressed with the new things that they saw, but were familiar with the equipment. Richardson and Anders (1994) noted that study of teacher change should include classroom observations, interviews at the outset and end, and a follow-up study (two to three years later). In this instance, teacher change as well as student change was noted over the span of this study.

Remarks group A-viii-A6 5 of 5. Teacher A found that digital microscopy was a way to “become more educated.” The teacher added that “they are a little [more comfortable with the digital microscope] … before it was like a total ‘wow!’ … and now it is ‘wow’ but the students are in more control.” And the teacher stated that students now “have more say-so in what they are discovering.” The researcher noted that the teacher was making a distinction between two different discovery processes. The first one was when the students were first introduced to the digital microscope and then did the first lesson. The next was when the students did the same lesson after they had been using the microscope in other classes. In this regard, the teacher discovered that the students still have that ‘wow factor,’ but in a different way. The researcher noted that because the students were familiar with the microscope, the students were more in control of their own learning when they use the digital microscope and could make better choices in what they wanted to observe, magnify, change, select, and photograph – and then draw.

In addition to the initial comments, the teacher expressed some concern that digital microscopy might “be a distraction on the elementary level, because they want to go do that instead of maybe what they should be doing.” However, the teacher added that students “feel confident that they all know [what it was like] when they did not have the aid of the [digital] microscope.” The teacher found that in the past when using the standard light microscope “some kids caught on and understood and other kids did not ... they never really totally understood what I was wanting them to get [because of the limitations of light microscopy].” The researcher noted that the teacher was concerned about when the students used the standard light microscope in previous lessons, some of the students caught on and understood and other students did not.

In teacher remarks about the digital microscope and *students*, Teacher A spoke about students being more familiar with the digital microscope after being exposed to it longer. As noted above, Herrenkohl and Guerra (1998), Krajcik et al. (1998), and Pearce (1999) showed improved metacognitive abilities in students after long-term exposure to project-based inquiry organized around a central theme or tool. Teacher A noted again that the students were still impressed with the new things that they saw, and their familiarity with the equipment had not diminished their enthusiasm.

Category – Teacher

Pre-interview 2004

About the digital microscope in relation to the teacher and the teacher's students, Teacher A anticipated that the class would show interest in "forensic science and about blood and different things under the microscope and that [those things] would be fun to look at [because that interested this teacher personally]." The teacher predicted that "once you start something [for example] if I put a flower underneath or a piece of clay for them to look at, they are going to be bringing me things and say things such as 'here, look at this,' 'here, look at this,' 'here, … [similar comments]' … [and] it will be exhausting; once students start looking at things, they can't stop." The teacher expected that lessons might involve "giving … kids a chance to look at… every thing because they will find [all kinds of things, for example] … 'here, look at this little piece of dirt on the floor.'" The teacher also anticipated "a lot of interest" in digital microscopy among teachers and students and added that "a lot of people are going to want to find out 'how can I use it?'" The teacher thought that digital microscopy in the classroom would be "quite fascinating" in part because the teacher had found "the light microscope [to be] fascinating." The teacher "imagined the [students] will all be going crazy" during the planned lessons. Also, the teacher noted that "the whole class [will see] things up close … in a different view that they normally show them" and this will allow "other people [to see] how an artist thinks … what they really see." And, the teacher hoped "students] would have a greater understanding of how an artist can have dreams and visions." And, the teacher expected that "[I might] make a whole book on that [exploration of the art environment]."

About the digital microscope in relation to the teacher and other teachers, Teacher A anticipated “I will try to see if the music teacher would want to compose the music [to go along with digital microscope art].” The teacher thought that other teachers would “encourage some of their [students] to use it and look close at it even if they have one in the room” and that the teacher would “encourage other teachers to try it [use the digital microscope to look at things up close in a different view that they normally show them].” The teacher expected that “if we [the teachers] hadn’t given them [students] the opportunity [to use the digital microscope] then they wouldn’t know [what you can see with the digital microscope].” The teacher anticipated that in order for teachers to have an opportunity to work together with digital microscopy, the collaboration must “make that connection other than just having speakers come in and show slides and whatever; that is always really neat but I think the fact that it is a project where it is a journey [that it evolves].” The teacher felt that digital microscopy would be a way for teachers “to give kids a new way to think and learn.” The teacher also predicted that the digital microscope “does do some really great things” for teachers and that teachers “will want to know how to use it.” The teacher anticipated that the teacher could “see the [students] say … ‘look at this’ [potential art object] … ‘can we look at this under the microscope?’” And, the teacher asked “how do the teachers [know] how the teachers [will] approach” the way in which teachers gain insight into how students develop an interest in science? The teacher thought the answer was that teachers may gain insight into student interests by doing “some videotaping so that you can capture their voices” and what is going on, or by “observing students … watching them, taking some notes, even taking pictures of them looking into the microscope.”

About the digital microscope and the teacher, Teacher A anticipated the new technology "would not be a more difficult way to teach the [students]" and that the teacher would be "going to teach them that it is a pretty cool thing and they are going to want more." Speaking about art, the teacher stated that "art in particular it is a lot about texture, [which] shows the children another perspective that we have not been able to touch through our curriculum." The teacher anticipated that now "teachers can observe how the students approach [art and inquiry] using the microscope." The teacher expected that the teacher would "see how the students interact with each other once they see what they see." The teacher predicted that at present those involved with implementing digital microscopy "don't quite know where it is going," which suggested that the teacher expected for them to have more direction in the future. The teacher added "because once you give it to the children you have to go [on into the lessons] with them; you just have to go on."

About the digital microscope in relation to the teacher and the scientist-teacher collaboration, Teacher A anticipated "I think the fact that we have some scientists working with us and teachers working with us on the other end, the students are in the middle … they are going to connect us with what we know and what you know, and there is going to be a great guidance [teacher feeling about collaboration] … it is going to be a learning experience I think the whole way … and we have expertise on both ends to help teach the kids." Then, the teacher expected "that once we [teachers] show them [students] how versatile it [the microscope] is … we [teachers] are going to have to set the boundaries because they [students] will have none." The teacher thought that "the kids are going to just bring things in" to look at with digital microscopy and that now students and teachers "have a piece of equipment that is easy to use."

Researcher summary (teacher) from pre-interview. In remarks coded in the category *teacher*, Teacher A spoke about what the teacher expected that the teacher and students would see and do using the digital microscope. Regarding the teacher and the teacher's students, Teacher A mentioned many specific things, including looking at forensic items and art-related objects, students bringing in items to look at, a high level of interest in using the digital microscope, and understanding how an artist might see an art object. Regarding the teacher and other teachers, Teacher A thought that other teachers and their students would be interested in using the digital microscope and that Teacher A would like to show other teachers this new technology. Regarding the teacher and art, Teacher A anticipated that students would view the digital microscope as 'cool' and that the new technology would give the students a new perspective on art, which might lead in directions where they are not sure where they are going. Regarding the teacher and the scientist-teacher collaboration, Teacher A predicted that students would benefit from being 'in the middle' of the collaboration and that the teacher and students would receive 'great guidance' from the collaboration.

Post-interview 2004

Remarks group A-ix-P4 1 of 5. Teacher A stated that "I gained an understanding of how Georgia O'Keeffe would take something and [work with it]… [the process was] sort of calming, and she would paint in such a large scale that she would make people stop and look and then [during the lesson] the kids were able to – I think – make that connection." The teacher commented on being personally pleased with the initial results of using “the digital microscope to teach a lesson about the artist Georgia O’Keeffe.” The researcher noted that Teacher A gained a greater understanding of and appreciation for the artist Georgia O’Keeffe by the use of the digital microscope. The teacher used the standard artist’s technique of employing a change in scale to a new version of that lesson using the digital microscope. The researcher noted that this in turn helped foster an understanding of what the artist (O’Keeffe) was trying to achieve with her paintings. The researcher noted that the teacher had earlier disclosed that the teacher had studied this artist, but it was not until the lesson using the digital microscope that this teacher gained a deeper understanding of going from a small scale to a large scale. It was important for this teacher to relate to what Georgia O’Keeffe said was her main objective in such large-scale paintings, specifically that such art would make people stop and look. The teacher found that by relating the lesson to using digital microscopes students were then able to make a connection to the artist through their own investigation of objects with levels of magnification. Teacher A remarked that the teacher specifically ‘used the digital microscope to teach a lesson about the artist Georgia O’Keeffe.”’ The researcher noted that the teacher had this art lesson in mind from the outset.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke that the teacher gained a better personal understanding of the artist Georgia O’Keeffe through using digital microscopy in the art lessons. Benke (2000) noted that the work of Georgia O’Keeffe was an immediate response to her environment. Benke reported that O’Keeffe was fascinated by flowers as a result of an art teacher’s bringing flowers to class one day during her early schooling in Madison, Wisconsin. Benke noted that the sight of a tiny flower inspired O’Keeffe to paint flowers that were magnified. Benke quotes O'Keeffe as saying: "A flower is relatively small … everyone has many associations with a flower – the idea of flowers … still in a way nobody sees a flower – really – it is too small – we haven't the time – and to see takes time … so, I said to myself – I'll paint what I see – what the flower is to me but I'll paint it big and they will be surprised into taking time to look at it – I will make even busy New Yorkers take time to see what I see of flowers" (Benke, 2000, p. 31). Richardson (1990; 1991) noted that teachers change in ways that are compatible with who they are as a person. Teacher A remarked on several occasions about her deep interest in Georgia O'Keeffe's work and her methods. Similar to these statements attributed to O'Keeffe by Benke, Teacher A also remarked on how the students made a similar connection using digital microscopy ('the kids were able to – I think – make that connection'). For Teacher A, the objective for students was much like O'Keeffe's objective with New Yorkers. Teacher A remarked that in 'using the digital microscope to teach a lesson' (examining flowers and shells), the students were able to make a connection with this artist's work.

Remarks group A-ix-P4 2 of 5. Teacher A stated that the teacher liked to "keep one [digital microscope set] up in the room just for the pure enjoyment of looking at things we use everyday [in art]." The teacher wanted to "see it [digital microscope] with all kinds of drawing aspects that I as a teacher hadn't tried before." The teacher stated that "having at least one [digital microscope] out all the time in here if somebody wants to do that then I [teacher] would have it already set up." The researcher noted that the teacher was conscious of the environment, everyday use of things in art, and the word 'enjoyment', which – the researcher noted – connected the digital microscope to the enjoyment of everyday things. This art teacher provided the setting for the students to share in the enthusiasm that the teacher found using the digital microscope. The researcher noted a change in instruction where the teacher recognized as significant the advantages of using the digital microscope with respect to drawing. By having the microscope out, visible, available, the teacher provided the opportunity for student use which is a change in lesson delivery. The digital microscope offered another outlet for students to try. The researcher noted that this teacher was very conscious of the setting of the room and how it could influence student behavior.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the teacher's having enjoyment in seeing everyday things using digital microscopy. Benke (2000), who carefully examined the life of Georgia O'Keeffe, noted that she used an "exalted way of seeing" (Benke, 2000, p. 37), which followed the view of the Romantic poet William Wordsworth. Wordsworth said "To every natural form, rock, fruit, or flower, even loose stones that cover the highway, I gave a moral life, I saw them feel, or linked them to some feeling" (Benke, 2000, p. 37). Teacher A, a student of O'Keeffe, similarly gained enjoyment from seeing everyday objects and natural things in a magnified or 'exalted' way. As Richardson (1990; 1991) suggested this was not so much a change for such a teacher, but rather the opportunity presenting itself for the teacher to bring out what was already within.

Remarks group A-ix-P4 3 of 5. Teacher A stated that with the digital microscope the teacher has "so many choices of things that we [teachers] could do." Further, the teacher found that using the digital microscope "went beyond the teacher's expectations." The teacher also noted that the digital microscope gave the opportunity to "have a team of people [teachers] trying out different ideas." Also, the teacher remarked that this teacher’s own experience with the standard light microscope was not related to what the teacher was doing now; it had to do with “looking at a drop of blood from my finger in high-school biology class.” The researcher noted that the teacher was aware that the digital microscope would allow for ‘more choices’ for the teacher and students. The researcher also noted that the teacher reflected on the collaboration with a team of teachers, which provided the opportunity to try out different ideas. And, the researcher noted that the teacher related microscopy to the teacher’s own experience with a standard light microscope and remembered that specific lesson. Also, the researcher noted the importance of having one’s own key experience in the use of the microscope, not as a passive learner but as someone who was actually doing the investigation.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the teacher’s excitement about digital microscopy and how the teacher wanted to convey that to other teachers. One of the ways that Teacher A expressed excitement about the digital microscope was to say that the teacher wanted to work with other teachers to share that excitement. Gosselin et al. (2003) discussed teacher collaborations (a working relationship among professionals) as a way to share resources and come up with emergent ideas about instruction. Whereas many collaborations include an outside person (for example, an external scientist; Cummings, 2004), the teacher referred here only to a collaboration of peers.

Remarks group A-ix-P4 4 of 5. Teacher A noted that the digital microscope allowed teachers to use “the big screen so that everybody can see.” The teacher also found that the digital microscopes’ computer monitors helped “let the teacher know if they [the students] do or they don’t understand something.” The researcher noted that the teacher made use of the' big screen monitor' (at the front of the classroom), which was possible because it was connected to a digital microscope. This was important to the teacher because the big screen made it possible for all (students and teacher) to see what was going on at the same time. Regarding the statement that the computer monitors allowed the teacher to determine if the students understood or not, the researcher found this statement revealing in that the teacher used this technology to check on students' 'understanding.'

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the teacher being informed by the computer monitor or the big screen in the room (both connected to digital microscopes) about what students were seeing, doing, and learning during art lessons. Pea (1994) noted that communication was of utmost importance in the inquiry classroom. In the instance of these comments, the communication was mainly visual, although clearly there were verbal and other communications as well. What Teacher A described would be called transformative communication by Pea (1994), who defined this as communication involving both thinking and knowing. As the teacher and most students were able to see computer monitors across the room and the big screen in the front, all participants were informed at one time in a transformative way. Teacher A noted this was positive for the teacher, but elsewhere this effect was noted as positive for the students as well.

Remarks group A-ix-P4 5 of 5. The teacher stated that digital microscopy allowed the teacher "to do some little in-services in our … school." And, the teacher found that the teacher could "show other teachers how we can use it on a daily basis." The researcher noted that the teacher was interested in sharing the digital microscope with other teachers. The words ‘daily basis’ goes back to the statement that the teacher made earlier about having a digital microscope set up in the art classroom at all times. The teacher expressed the view that this was something important for the teacher to share with other teachers. In addition, the teacher made a recommendation (from the teacher’s perspective) that it would be “really awesome to have two or three students to a microscope so that students would have a chance to use it.” And, the teacher again wanted to “get other teachers that weren’t involved [and find out if] they were interested” in digital microscopy for their classes. The researcher noted that the word ‘awesome’ reflected the excitement that the teacher had for the digital microscopes. The teacher saw a need to have more digital microscopes available so that the students could work either as pairs or in small groups. The teacher thought it was important for all students to have a chance to use the digital microscope as they wanted. The researcher again noted that the teacher was interested in sharing the digital microscope with other teachers who were not previously using digital microscopy, but that the teacher thought would be interested. The researcher noted that the teacher wanted to share with other teachers and collaborate. Also, about future planning, the teacher remarked “[I want to] figure out what’s the next area that I really want to focus on” for work with digital microscopy. The researcher noted that the teacher was considering implementing the digital microscope in other lessons and areas of the school’s curriculum.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the teacher wanting all students in the class to have a chance to use the digital microscope and the teacher’s desire to share ideas about using the digital microscope in the art classroom with other teachers. Liem (1987) pointed out the importance of students having equitable access to equipment in the inquiry-based classroom. Teacher A organized the art lessons so that each student had equal access. Roth (1996b) noted that introduction of a new tool transformed the inquiry classroom and that there was a natural competition for access to the new tool. However, Roth pointed out that with additional tools and with time, all classroom actors, principal and peripheral, were engaged fully in the inquiry activity. By providing enough time and several tools (digital microscopes), Teacher A reduced the time required to engage all actors (students). As noted previously, Gosselin et al. (2003) discussed teacher-teacher collaborations (a working relationship among professionals) as a way to come up with creative, emergent ideas about instruction. According to Richardson's (1990; 1991) theory of teacher background in teacher change, Teacher A might have been predisposed to this kind of interaction among teachers from earlier experiences.

Post-interview 2006

Remarks group A-ix-P6 1 of 5. Teacher A stated that "I learned quickly that I needed to have one whole class where we just explored and then the second time – we still had kids wanting to explore more and not being able to focus as much – but now that we have used them a couple of years, more of them have used the microscopes." However, the teacher found that "not to allow enough time" with digital microscopy was still a problem. The teacher added that "there was so many "oh wow!" kind of things that I could not get them to move on to do the art part … and I had a limited forty five-minute period [when] I had intended to introduce an artist, let them look at some flowers and shells, and take a picture … well, that just was not going to happen!" The teacher added that "[I] think the microscope is a good tool, [and] I think this digital [microscope] was the best for what I have seen because it was so easy for them to handle.” The researcher noted that the teacher learned something about the students by using the digital microscope in art lessons because the students needed to ‘just explore’ first. The need for exploration time was observed again when the students used the microscope for the second time and the students had problems focusing on the lesson in the time allotted. The researcher observed that time was a problem, especially in a limited forty-five minute period. The students were informing the teacher by their actions that they needed more time for learning in this kind of setting when working on inquiry lessons with the digital microscope. The teacher revealed that being ‘easy to handle’ was an important consideration in the selection of tools to use in an art lesson.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the need for extra student exploration time using the digital microscope before students can focus on completing their lessons. Jones et al. (2000) wrote about students and their need for what they called conversation space in addition to what they called tool space. In conversation space, the students discussed what was going on and what was learned from each other and adapted to the new tool(s). In tool space, the students worked with tools in order to be proficient with them in the same way that the students became proficient in conversation. Roth (1996b) remarked on a similar phenomenon when describing the transformation of an inquiry classroom by the introduction of a new tool. The students rapidly adapted to the new tool, but this took time for all to adjust. Specifically, the principal actors in the classroom had to interact with the peripheral actors and draw them into the discourse and use of the new tool. Teacher A noted this reaction of students who wanted ‘exploration time’ as the teacher put it, to gain understanding and proficiency with the digital microscope.

Remarks group A-ix-P6 2 of 5. The teacher would like to “have a web-site set up so that you could pair [up students for homework assignments so that] our little kids could be paired with the big kids.” Further, the teacher stated that the teacher would like to “have a collaborative project with a university and then with fellow teachers.” The researcher noted that the teacher had made several revelations here. The teacher mentioned for the first time a ‘web-site’ and ‘pairing’ younger students with older students. These statements showed a potential for change in classroom set up. This change would go outside the actual classroom and could expand to a virtual classroom where the students were not limited to the grade or class that they were in but could include other students in other grade levels. The teacher wanted to set up a web-site for the lesson. This in turn could be shared with many others. The researcher noted that the use of digital microscopes allowed for this kind of expansion beyond the actual walls of the classroom. In this scenario, collaboration was now possible without the time or space constraints but only the constraint of accessibility to a computer and the Internet. The researcher noted that this was an important change in thinking by the teacher and was not anticipated at the outset. As for the last comment, the researcher noted that this was significant that the teacher mentioned the importance of collaboration with a university and with fellow teachers. This showed a change in the people that this teacher considered collaborating with.

In addition, the teacher stated that “[I did] not know exactly what to expect, to tell you the truth, at the beginning – the whole thing – I [am] pleased with the progress we have made.” The teacher also would “wish we had more time to be able to collaborate even more.” The researcher noted that, although the teacher did not know what to expect, the teacher was ‘pleased’ and mentioned that there was progress made. The researcher noted that time affected other things beyond the classroom and that it extended into the collaboration with other teachers and the entire project. Time was a consideration because the teacher wanted to ‘collaborate even more.’

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the teacher’s desire to have a web-site for sharing digital microscopy and collaborative projects with ‘a university and fellow teachers.’ Teacher A’s comments about a web-site and collaborative projects both were rooted in the teacher’s desire to share information about digital microscopy. The Internet had been an effective medium for teacher sharing of specific projects, including those related to microscope science (Bell & Linn, 2000; Davidson, 1998–2004; Slattery et al., 1999). In particular, Davidson (1995-2004) showed the effectiveness of web-sites sharing digital microscope imagery for education. Teacher A wanted to do something similar but perhaps on a smaller scale. As noted previously, Gosselin et al. (2003) discussed teacher collaborations (with other teachers and professionals) and their effectiveness. As they noted, these collaborations were particularly effective when the teachers involved had common goals and shared equipment. As noted previously, Richardson (1990; 1991) expressed the view that teacher background was preeminent in teacher change. So, Teacher A might have been predisposed to such collaborative activities among teachers and other professionals from earlier experiences.

Remarks group A-ix-P6 3 of 5. Teacher A stated that digital microscopy was a way that “allowed me just to look at it through the children’s eyes too – as well as the microscope’s eyes.” The teacher also mentioned digital microscopy allowed the teacher to “be able to see in a different way that I had not seen [before]” and “it showed me things that I could not see!” The teacher found that “[I was] comfortable with it and the computer too” and that digital microscopy was a way “to become much more comfortable with the microscope.” Regarding seeing through the children’s and the microscope’s eyes, the researcher noted that this was an important statement by the teacher, about how the digital microscope allowed the teacher to be able to see in different ways. This showed a change in discovering what a student saw, was interested in, wanted to share with others, and wanted to capture in a picture, which was not possible using the standard light microscope. And, the researcher noted that this represented a change, specifically, that the teacher could see in different way – more like the digital microscope ‘sees.’ The researcher noted that even though the teacher had used other means of magnification for this lesson (such as the standard light microscope and the magnifying glass); the digital microscope showed the teacher things that the teacher could not see previously or showed the teacher in a different way. Regarding the teacher’s ‘comfort’ with the digital microscope, the researcher noted by these two statements that the teacher clearly affirmed being much more comfortable with the digital microscope and the computers related to it. The researcher noted that the teacher’s comfort level changed over time by continually using the digital microscope.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the teacher: being able to look at things through the students’ eyes by using the digital microscope's 'eyes;' discovering what the student saw, was interested in, and wanted to share with others; changing the teacher's way of seeing as a result of this lesson; and sharing the excitement of authentic discovery in this lesson. Citing the ancient Greek view, Smith and the Drawing Study Group (1998) likened drawing to scientific inquiry. As Pestrong (1994) and Wright (2000) pointed out, artistic representations that have a scientific quality as well require decoding as to the scientific meaning. As Teacher A's students composed images and later made drawings, sketches, or paintings based on the images, they were looking for deeper meaning. Teacher A noted that the teacher saw with eyes more like the students' when using the digital microscope. This remarkable 'different view' in photomicrography had been the thesis of several popular works including Rotner and Olivo's (1997) *Close Closer Closest* and similar largely photographic works by Davidson and Lotus (1993) and Dabdoub (2003). In particular, the digital microscope view was a very precise and detailed view that could be faithfully captured by the imaging components of the digital microscope technology (Davidson, 1995-2004; Prime Entertainment, 2002). In Piagetian terms, the digital microscope allowed students, regardless of their level of development, to make digital images that had intellectual realism (Krampen, 1991), meaning that the images contain all details even if they are not immediately noticeable or visible at first glance. These images immediately provided students with graphic representations that might be beyond their level of development in terms of capacity to draw. For the teacher, the digital microscope views and digital images also had a realism that Teacher A expressed as being able to see through 'different eyes' and 'through the students' eyes.' Teacher A remarked that the teacher was able to see (understand) better what the students were interested in and wanted to share. Liem (1987) described this kind of teacher engagement with students, which included sharing the excitement, as being key to good inquiry lesson development. As noted previously, Jones et al. (2000) found that it was important for students to have access to tools, but also important was the students' choice of what to do with the tools. In these art lessons, Teacher A had done that with the students. In authentic scientific inquiry, Rahm et al. (2003) referred to the property of emergence, which meant that something unexpected comes out of the inquiry. It is reasonable to assume that the same emergence would occur in a similarly structured art inquiry lesson, a phenomenon that could be called authentic art inquiry. Teacher A appeared to have achieved this in the digital microscope art lessons described here.

Remarks group A-ix-P6 4 of 5. Teacher A stated that digital microscopy would "encourage us to keep … to maybe try to buy, even more [digital microscopes] so that maybe we could have more of them in the classrooms, not just in the lab … it is wonderful to have enough for the lab that is a big plus … but I think if we had even more that were out in the building, then you could even just try … that would be really nice." The teacher also remarked "see, oh wow, you could connect it with this or you could connect it with that … but, again, then maybe the web-site may allow that too." Further, Teacher A commented that in digital microscopy that "potential is out there, you just have to keep working at it." The researcher noted that the digital microscopes were used more in the lab because that was where they were placed (rather than in individual teacher's classrooms) so that more teachers could access them through the lab. However, Teacher A still would like to buy more for the classrooms and this reinforced what the teacher previously said that it would be important to have a microscope out in the classroom available for the students or the teacher. The researcher noted that the teacher remarked ‘oh wow’ again and this time in reference to how many connections could be made with the digital microscope and different lessons and through the web-site. The teacher again referred to the web-site, which again showed a change in how the teacher was thinking of ways to use the digital microscope in different lessons and on-line. The researcher noted that the teacher used the word ‘potential’ which showed that the teacher was continuing to think about how the digital microscope could be used in the classroom, with other teachers, and as part of a web-site. Further, this teacher was considering that there was the potential for things not yet thought about.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the many potential connections of the digital microscope. Teacher A’s comments about a web-site were rooted in the teacher’s desire to share information about digital microscopy, which was in turn related to the success of the digital microscope in this teacher’s view. Davidson (1995-2004) showed the effectiveness of web-sites sharing digital microscope imagery for education. As noted previously, Richardson (1990; 1991) expressed the view that teacher background is preeminent in teacher change. So, it might have been that Teacher A was predisposed to this kind of outreach potential from the teacher’s past.

Remarks group A-ix-P6 5 of 5. Teacher A stated that using digital microscopy caused the teacher to “wish for maybe even more workshops where [teachers] could get together and share projects that people have done … that type of thing.” The teacher also found that the teacher would like to “see how people have their room set up where they can leave it out and have it used on a daily basis” and “how people store the information.” The researcher noted that the teacher had an interest in attending workshops to collaborate and share projects that other people have done. Again, collaboration was mentioned as something that this teacher would like, which would benefit not only the teacher but the other teachers. What those teachers might bring out of the workshop would be a result of the sharing of ideas. The researcher observed that the teacher was interested in room set-up and the results of leaving a digital microscope out on a table on a daily basis. The teacher was interested in how other teachers used the digital microscope in their classrooms and in finding out how other classrooms were set-up and how information was stored. The teacher mentioned these things previously with regard to the teacher’s own classroom, but now mentioned expanded gathering of information beyond the art classroom that might help in the integration of the digital microscope in other classrooms.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about having teacher workshops and sharing projects related to digital microscopy. Teacher A’s comments about wanting to have a workshop and exchange ideas among teachers were rooted in the teacher’s desire to share information about digital microscopy. As noted previously, Gosselin et al. (2003) discussed teacher collaborations and their effectiveness in spreading ideas. Richardson (1990; 1991) expressed the view that teacher background was preeminent in teacher change.

Interview after first lesson 2004

Remarks group A-ix-A4 1 of 6. Teacher A stated that “[I] printed the pictures for the students on a little bit better quality paper … a matte finish versus the shiny paper.” The teacher found that the teacher “gives the students a little assignment project – really simple because they are just in the second and third grade – the procedures in the lab [assignments are] to select a shell and examine it under the digital [microscope] and use the digital [microscope] to look closely at your item and select an interesting view that would be in the style of Georgia O'Keeffe." The researcher noted that the quality of the paper that the pictures were printed on mattered to this teacher. Also, the researcher noted that the teacher used the word 'simple' for the lesson for the second or third grade. The teacher gave 'simple directions' involving four steps. The researcher noted that the teacher was in control of what the students were to do in the lesson. In addition, the teacher stated that "both of those things together … the ability to see something up really close … [and] being able to take the picture is exactly what we teachers needed." The teacher also remarked that "these really enlarged kind of pictures [are] like [art that] Georgia O'Keeffe would do." The researcher noted that the teacher showed an interest in the technology offered by the digital microscope. Specifically, the combination of 'the ability to see something up really close and then being able to take a picture' was particularly important to this teacher.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the teacher's art lessons on Georgia O'Keeffe and how well the lessons are done using the digital microscope. Teacher A remarked on several occasions about the teacher's deep interest in Georgia O'Keeffe's work and her methods. Richardson (1990; 1991) noted that teachers change in ways that were compatible with 'who they are as a person.' The statements quoted previously and attributed to O'Keeffe by Benke (2000) were similar to Teacher A's view of this lesson for the art students. For Teacher A the objective for students was much like O'Keeffe's objective of examining things closely. In this way, the digital microscope was an appropriate tool for this purpose.

Remarks group A-ix-A4 2 of 6. Teacher A described the teacher's view of "what kids see" by saying: "they were interested in the shapes and the textures and in the patterns that they were seeing … and I think they were seeking that … they switched things many times, items like shells and flowers … and if we were to go back and look back on the computer where they worked we would see several images, they did not take just one, they took several." The teacher added "in fact I had anticipated that we would do part of the lesson in the lab and then stop and then come back to the art room to do a component in the art room to draw … [but] I could not get them to stop [working in the laboratory]." About this level of student interest, the teacher stated "not that they were disobeying, but they were just trying so hard, and they wanted to save both pictures, so they wanted the shell and the flower … they were excited and they wanted it all … it was hard to get them to stop, so I just changed my plan … [we] just stayed in the lab … and [I] tried to let them to sketch in the lab and that was a little tedious because the space was not adequate for drawing." The researcher noted that the teacher changed the lesson plan because it was difficult to get the students to stop the digital microscope work because they were so excited. The teacher also made discoveries about what interested the students and what they saw. The teacher noted the students were interested in the shapes, textures, and patterns that they were seeing and that the teacher knew what they were seeing because of the ability to observe them. The teacher observed that the students switched things many times, both shells and flowers. The teacher was able to go back and look on the computers' hard drive where they worked and found multiple images made by students. The researcher noted that the digital microscope not only helped the teacher observe how the students worked (by observing what was on their computer monitors or listening to their responses and conversation) but also the digital memory on the computer also assisted the teacher to take a look back later on. The researcher noted that the teacher had anticipated that the students would do part of the lesson in the lab and then do the drawing part in the art room, but the teacher had to change the lesson because the students did not want to leave the laboratory where the digital microscopes were located. Also, because the students wanted to work with both the flower and the shell, the teacher had to change the lesson to accommodate both art objects for each student. The researcher noted that the art lesson provided an insight into how students learn, what they do when they get excited about a lesson, and how they manipulate the materials so that they could 'see' the object in a different view. These things were not evident in previous art lessons done without the digital microscope.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about many things including: how the digital microscope helped the teacher gain insight into how students see and learn, what the students get excited about in a lesson, and how they manipulate the objects so that they can see the object in a different view; how teacher observed students switching objects back and forth many times (the shells and the flowers) and how the teacher observed students being interested in the shapes, textures, and patterns that they were seeing; how the technology of the digital microscope helped the teacher observe students (by looking at what they had on their computer monitors and listening to their discourse concerning what they were seeing and doing (plus, the teacher's being able to take a look back later on through the students' saved image files);

how the art lesson evolved as the students worked because their interests changed the lesson's originally planned direction; how the students were so motivated that the teacher could not get them to stop working on the lesson; how the students took more than one picture of the object and had a difficult time selecting just one digital image to be printed; and how the teacher responded to all this. Teacher A found that the teacher saw with eyes more like the students' when using the digital microscope. This remarkable 'different view' in photomicrography had been shown in some popular works including books by Davidson and Lotus (1993), Rotner and Olivo (1997), and Dabdoub (2003). Digital microscopy gave a very precise and detailed view that could not be duplicated without large, complex laboratory equipment (Davidson, 1995-2004; Prime Entertainment, 2002). Teacher A saw the students manipulating and touching objects, which also has a place in the Piagetian view of children's conceptions about objects. Piaget originally introduced the concept of haptic perception (Krampen, 1991), which had been more recently studied and reviewed by Jones et al. (2003) who watched as children worked with microscopes. In haptic perception, the student needs to touch and feel the object as well as see it at different scales to better understand its properties and nature. Teacher A reported students switching objects and observing shapes, textures, and patterns of many things. Roth et al. (1999) noted that focal artifacts and new tools alike stimulated social interaction in the inquiry classroom. This social interaction (discourse, gesturing, and body language) stimulated shifts in attention and student focus, which was manifested here in students' switching art objects and moving to new explorations of shape, texture, and patterns that were being discovered among the students. Liem (1987) noted that an effective inquiry teacher constantly monitored students' progress and interacted with students. Teacher A found that the teacher was doing this and how well the computer monitors allowed the teacher to do this aspect of directing the inquiry and participating in it. The phenomenon of the students not wanting to stop working on the art lesson might have been an entirely new experience for Teacher A, but the teacher changed the structure of the planned lesson to accommodate student interest and excitement to the extent that was possible. This teacher change in view of the lesson, which was more student-driven at this point, was compatible with the teacher's background and perceptions of practicality and appropriateness to the situation (Richardson, 1991). Roth (1996b) found that introduction of a new tool could so transform a classroom that the students became completely caught up in the community learning process. In this instance, Teacher A experienced this effect alongside the students and allowed the lesson to evolve according to student interest, which was an effective inquiry lesson according to Liem (1987).

Remarks group A-ix-A4 3 of 6. Teacher A stated that the digital microscope was a way to "have a great tool" for learning and exploring and also mentioned that it was important for teachers "not to race through the microscope lesson because the kids want to explore … to experiment … to be scientists more … to see in a different way … to enjoy doing it" (referring to digital microscopy). The researcher noted that the teacher gained this information by observing what the students did, what they said, what they took pictures of, and how they manipulated the art objects – all of which helped the teacher find out how students learn. The teacher was able to gain this information because the digital microscope provided the ability to 'see' what the students were 'seeing' and the ability to 'see' how they explored. In addition, the teacher thought that digital microscopy was a way to "obtain results that have never been this good on this level" (referring second and third grade students). The teacher added that the teacher would like "to hear the photographer's side of what … [a] teacher can do with the digital [microscope]." The researcher noted that this statement was one of the most important ones about the success of this lesson. The digital microscope helped the teacher obtain results that have never been this good on this level. Also, the researcher noted that the teacher was curious to see what a photographer would do using the digital microscope and what the results would be. The researcher noted that this was an important statement as it showed that the teacher was thinking beyond the classroom and considering information at a different level of professional growth and knowledge, which the teacher could then use in future lessons.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about several things including: how the teacher observed that students needed time to discover and should not be 'raced through' the microscope lesson; how the teacher learned that students wanted to explore, wanted to experiment, wanted to be more like scientists, and enjoyed doing these things; how the teacher as participant observer gained insight by observing what the students did and what they said (as well as what images they made0, how they manipulated the objects, and how they made images of art objects; how the digital microscope provided the ability to 'see' what the students were 'seeing' and the ability to 'see' how they explored; how the teacher could experience professional growth and gain new knowledge by using the digital microscope (and how it compares to photography); and how 'the digital microscope helped the teacher obtain results that have never been this good on this level.' Students who were actively engaged in the art lesson showed the teacher that they needed more time to explore and discover. They expressed that they did not want to have to 'race though' the lesson. Teacher A was willing to change plans for the lesson to accommodate student interest, which was the mark of an effective inquiry teacher (Liem, 1987). In *Nurturing Inquiry*, Pearce (1999) noted that every child was a scientist. By extension to the art lesson at hand, it was also evident that every child seemed to be an artist as well. This made sense in view of the close connection between art and science at this level (Wright, 2000). Teacher A closely observed and participated with students in the lesson and allowed the lesson to become more student-driven, which was an effective inquiry strategy (Cornell, 1998; Liem, 1987). The teacher's opinion that the digital microscope might provide a view that was more like a child's way of seeing may be supported in Piagetian theory (Kampen, 1991). At the age of most of the art students in this instance, the students were entering the Piagetian stage of intellectual realism (Krampen, 1991), a stage where details appear to children right away – details that may not emerge at first to the casual observer (Krampen, 1991). Teacher A saw the students manipulating and touching objects, which has to do with Piagetian haptic perception (Jones et al., 2003; Krampen, 1991). In haptic perception, the student wants to touch and feel the object as well as see it at different magnifications in order to better understand its properties. Teacher A had a confident feeling about digital microscopy and suggested here that the teacher would like to reach out to a photographic professional to share ideas. Teacher A was expressing a feeling of confidence by these statements (Richardson, 1991). Teacher A also mentioned 'results never seen before' in the art lessons. This also was an important expression of confidence and an affirmation of the teacher's decision to change methods in these art lessons (Richardson, 1991).

Remarks group A-ix-A4 4 of 6. Teacher A stated that the teacher was “pleased … excited … [and] knew it was going to be fun, but … not sure how fun.” The teacher found that digital microscopy was a way for… a teacher to “be excited … in fact when they took the pictures that day in class, I could not wait … I went to the store and bought paper that night and came back to school late and printed these pictures because I could not stand it … I wanted to be able to show everybody … I did not want to drag them to a computer even … I wanted to show them and show the children and I wanted to do the next step [the drawing of the shell or flower onto larger paper] … it was so fantastic, you know … it was so great!” Teacher A remarked that digital microscopy “makes me the teacher want to do more” and to “stay on target with what we are supposed to be doing.” The researcher noted that although the teacher anticipated that digital microscopy was going to be ‘fun,’ with the introduction the digital microscope, the teacher was not sure of how much fun students (and teacher) would have. The researcher noted that the teacher was pleased because the students were excited to use the digital microscope and that they enjoyed working with it. About the teacher’s excitement, the researcher noted the words expressed in these statements related how successful the teacher thought the lesson was. The researcher noted that the teacher was telling the researcher what the teacher does when the teacher is excited about a lesson. These were some remarkable phrases used by the teacher in this regard: ‘be excited,’ ‘could not wait,’ ‘came back to school late,’ ‘printed these pictures because I could not stand to wait,’ ‘wanted to be able to show everybody,’ ‘did not want to drag them to a computer,’ ‘wanted to show the children,’ ‘wanted to do the next step – drawing on large paper,’ ‘it was fantastic,’ and ‘it was so great!’ The researcher could feel the excitement and enthusiasm through the teacher’s words describing what the teacher physically did that revealed that the teacher also was intrigued by the lesson using the digital microscope. The researcher noted the parallel learning and enthusiasm that occurred with this teacher. The teacher and the students seemed to experience similar behaviors and similar excitement and similar sharing and enthusiasm. The teacher's excitement informed the researcher what a teacher would do or would say about the digital microscope, which in turn provided a view into what the students do or say. The researcher noted that the experience the teacher had was very important. The teacher's enthusiasm and actions perhaps mirrored the actions of what the students felt. The teacher's excitement, desire to share, and wanting to stay up late (a noteworthy action for a teacher whose day starts early) showed how the teacher gained an insight into the discovery process. The teacher likely hoped to observe the same excitement in students in the digital microscope art lessons. Now, the teacher knew what it felt like to be so excited that the teacher did not want to stop or wait until the next day. The teacher then could relate to what the students experience when they used the digital microscope for exploration of something that they were interested in and wanted more time to explore. Regarding staying on target, the researcher noted that the teacher was aware of the responsibilities that a curriculum needed to 'stay on target with what we are supposed to be doing.' The researcher noted that even though Teacher A mentioned that digital microscopy 'makes me want to do more,' the bottom line was that the teacher still needed to be aware of guidelines and curriculum timelines. Teacher A again expressed that time constraints affected what was taught and for how long. The researcher noted that the digital microscope helped the teacher want to do more and the change was that it motivated the teacher to want to do more.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the teacher's excitement regarding the success of the art lessons and the high quality imagery that the students produced during the art lessons. In discussing teacher change (such as the change in this instance from traditional art tools to the digital microscope), Richardson (1990; 1991) noted that the decision to embrace change lay in a teacher's beliefs, attitudes, goals, and knowledge and cues from the organizational environment. Teacher A's statements in this instance and previously suggested that the teacher believed that there was a better way to convey the art lessons to studies and that the teacher's attitude and goals inspired the teacher to try to do this. The teacher's knowledge of the style of Georgia O'Keeffe, which was a personal study of the teacher's, encouraged the teacher as well. Lastly, the organizational environment of the school indicated to the teacher that they should continually look for ways to improve instruction. All these things made the success of the digital microscope-based art lessons very exciting to the teacher, and the teacher expressed these feelings in this instance.

Remarks group A-ix-A4 5 of 6. Teacher A went on to say that "what kids see, I think what they noticed, is they went … many of them … for white objects, which I thought was very interesting … I really thought most of them were going to go for the colored flowers and all … but if you notice a good many of them selected the white shells and the white flowers versus the pink … and I found that to be interesting." Reflecting on the students' selection of white objects for digital microscopy, the teacher added that "I would think that would have been the most difficult." The researcher noted how the teacher commented on the selection of white objects which the teacher thought would be the most difficult by the students. The teacher's preconceptions were changed as the students selected objects that were not the ones the teacher would have thought the students would have selected.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the teacher's expectations on what art objects the students would choose to work with and how the teacher was wrong. Barab and Hay (2001) pointed out that students enjoy a sense of ownership of findings based on inquiry lessons. One of the aspects of that sense of ownership was the decision of students about what things to investigate as they designed their own line of inquiry (Pea, 1994). Teacher A expected the students to focus on one thing (art objects with colors), yet the students largely chose another (art objects that were white). This independence of thought and action went along with the sense of ownership.

Remarks group A-ix-A4 6 of 6. Teacher A stated that digital microscopy had "triggered my mind … a project on Georgia O'Keeffe." Speaking of the results, the teacher commented: "I was amazed that they [the students did so well] … their compositions [were much like O'Keeffe's] … when they were seeing through the microscope, the view that they were seeing through the microscope, the view that they chose to keep as they are keeping pictures … most of them did not include the whole flower, so many of them would include part of [it] …like the center of the flower and part of the petals … but it was an off-centered kind of picture versus just a radial kind of [picture] from the middle kind of picture." The researcher noted that the digital microscope provided an inspiration for the teacher to change the lesson plans and to include one on the artist Georgia O'Keeffe. In this way, change from the traditional lesson was an inspirational idea that was 'triggered' in the teacher's mind. The researcher noted that digital microscopy provided change in the way of the teacher's wanting to do more and also thinking up new lessons utilizing the digital microscope. Change in this case was not only in forming a new lesson but also in inspiring a new lesson. Regarding the teacher being 'amazed' at the students' compositions, the researcher noted that these statements contained many revelations the teacher discovered about what students see using the microscope. The teacher was amazed at the students' art compositions, which revealed what they were seeing through the microscope. The researcher noted that the digital microscope provided the teacher with information about students. This included the view that what the students were interested in was on the computer monitors, the view they chose to keep was digitally saved and kept on file, the view that they captured (part of a flower – off center) provided the teacher with information about student's ways of seeing that the teacher did not have before using the digital microscope. The change that the teacher observed came from the students' use of the digital microscope, the manipulation of the microscope, the selection of the objects, the observing and viewing of the object, the actual way the students manipulated the object to view, the image that was captured, the selection of the image to print, and the drawing of the image. All of these helped the teacher to see what the students were seeing, and then what the students drew from their captured images.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about the teacher's inspiration to form an art lesson on Georgia O'Keeffe using digital microscopy. In earlier comments, Teacher A expressed that Georgia O'Keeffe was a personal favorite of the teacher's and that the teacher wanted to continue with art lessons for students using the O'Keeffe style. Considering Teacher A's interests and background, it seems likely that Teacher A would discover the digital microscope and the way it 'triggered the teacher's mind' many new uses for this new technology, including exploring the style of O'Keeffe. As noted previously, Benke (2000) described Georgia O'Keeffe's works as complete, large-size views of flowers and natural objects. Benke noted that the O'Keeffe style was "extreme close-up, as a result of which the outer edges of the leaves and stems are often cut off" (p. 31). Teacher A described this style to the students and then introduced them to the new technology of the digital microscope. Teacher A reported the results were images that showed how the digital microscope helped the students see deeply, which carried over to their drawings much like O'Keeffe's observations were evident in her drawings.

Interview after lessons 2006

Remarks group A-ix-A6 1 of 2. Regarding digital microscopy, Teacher A thought "it would be fun for even myself to let it influence my [own art] work, if I ever get to do any on my own time." The teacher added, "I think personally it is cool, and I wish I would use it even more than I do … [but there is a limitation] because elementary pace is so fast." Teacher A also stated "you know it is frustrating because there are so many things that you [could] do and you have to pick and choose and all … so, I know there were many more occasions when I could have used it." In addition, the teacher stated that digital microscopy requires planning and "getting into the lab … [where the previous] teacher was very willing to change places with me, but it requires one more step; you know, setting up a date and getting everybody in there." The researcher noted that the teacher used the word 'fun' to describe the experience of using the digital microscope and that by using the digital microscope to create art on the teacher's own time, it could influence the teacher's work. The researcher noted that the teacher used the word 'cool' to describe feelings about using the digital microscope. The researcher noted that the teacher needed more time to use it as much as the teacher would like. The teacher mentioned 'frustration' in that there were so many things that a teacher could do (regarding use of the digital microscope) and that a teacher must pick and choose due to time constraints. The researcher noted that the teacher would like to use digital microscopy on more occasions if there were more time. The researcher noted that the issue of having enough time was also compounded by trying to share the computer lab with other teachers.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about how the digital microscope would change some things the teacher did (the teacher's own art work and other art lessons) if there were more time available. Teacher A's comments about what the teacher would do 'if there were enough time' were expressions of potential change that the teacher would be willing to make or might make in the future. Richardson (1990; 1991) noted that teachers change in ways that were compatible with their backgrounds and who they were as a person. Teacher A noted that time was a real consideration and needed to be included for future planning and implementation of some of the changes that the teacher listed.

Remarks group A-ix-A6 2 of 2. Teacher A stated that "[I] think that [digital microscopy] really helped the students connect [to art]" and that digital microscopy "helped me to see that they really needed to see [things using this new method] … I mean, I could not be their eyes [so they needed something else]." The teacher added that digital microscopy "helped me to understand that they really needed that visual [stimulation], and to be able to touch, that tactile part too." The teacher added digital microscopy helped the teacher and the students "to be able to really touch it and use it." Further, the teacher noted that there was value in being able "to point and say 'yes, that is true' and 'look at this' … and you could really point [to magnified things], but you cannot be someone else's eyes." The teacher added that "to point at something and say 'see' and somebody else can say 'yes,' ... but having the microscope – and the [computer] monitor – you could really see, *you know it was there!*" The researcher noted that the teacher learned through observation that it was important for students to do their own observing. From past experience, the teacher realized that a teacher could not depend on what the teacher saw under the microscope being the same thing that the students would see. This was discovered previously when using the standard light microscope. In that instance, the teacher would select the object and select the correct focus according to the teacher's vision, but that did not work well in the art lessons. After using the digital microscope, the teacher discovered that it was important for the students to do the selecting, focusing, and observing. The researcher noted that the teacher also discovered that for the students to be able to touch the object was as important as being able to see the object under magnification. The teacher learned that the students needed visual and tactile experiences when using the digital microscope. Regarding the teacher's comment 'you cannot be another person's eyes,' the researcher noted that using the digital microscope allowed the user to be able to point to what they were seeing and to interact with others and to include them in the observation. By having the computer monitor visible, the teacher found that it enabled discourse to take place.

In teacher remarks about the digital microscope and *teacher*, Teacher A spoke about several things, including: the teacher learning that it was important for students to do their own selecting, focusing, and observing; the teacher discovering the importance of the students touching the object as well as being able to see the object under magnification; the teacher's observation that 'you cannot be someone else's eyes;' the computer monitor allowing the user to be able to point to what they are seeing and interact with others and include them in the observation; and the teacher and the students working together on the lesson as it was going on. Following good practice in inquiry (Liem, 1987), Teacher A allowed students to select their own art objects for study. This gave students a sense of ownership of the lessons' findings and imagery (Barab & Hay, 2001) and added excitement to the lesson. As noted previously, Jones et al. (2003) reported that students obtained a haptic perception of objects (a Piagetian concept) when they both handled and viewed objects microscopically. This haptic perception was judged very important in students' understanding of the physical properties of the objects examined (Jones et al., 2003). As noted previously, Roth (1996b) noted that the physical manipulation of objects was part of the physical gesturing that he noted as significant among students who were engaged in inquiry lessons. Teacher A noted this among the students in the art classes and incorporated this in the art lessons. Teacher A also found that being able to point to digital microscope imagery on the computer monitors as the work was going on was important to student understanding and teacher-student interaction. This kind of teacher-mediated inquiry was particularly effective (Pearce, 1999), and the teacher noted how the new technology made this possible. Roth et al. (1999) found that students needed a forum for inquiry in order to share common experiences in the inquiry classroom and keep discourse going. The computer monitors, which showed the view of the digital microscope in real time, provided such stimulation to the classroom community. Teacher A stated that ‘you cannot be someone else’s eyes’ in reference to the students’ needing to look for themselves, which was aided greatly by the configuration of the digital microscope and its related computer monitors (Davidson, 1995-2004). The digital microscope lesson with art objects developed into a type of teacher-student partnership (Marek, 2002), which had benefits for both teacher and students.

V. FINDINGS AND RESULTS

Overview

This chapter addresses the research questions of this study based on the teacher's coded remarks, the researcher's comments on those remarks, and the literature connections for those remarks. In their interviews with the researcher, both teachers spoke through the semantic domain categories in addressing the effects of using digital microscopy in their respective elementary enrichment and art lessons. In so doing, the teachers provided data about their thoughts, feelings, and insights on the digital microscope, their digital microscope lessons, related computer equipment, and the behavior and discourse of their students. The researcher reviewed the teachers' coded remarks and their literature connections in order to make pertinent comments on the remarks (presented in Chapter IV) and to formulate responses to the three research questions (in this chapter). In compiling responses to the research questions, which form the main part of this chapter, the researcher wanted to define and describe the emergent culture of the respective enrichment and art classrooms during digital microscope lessons. Specific responses to the research questions were formulated from all of the interview remarks groups, reviewer comments on the remarks groups, and literature connections for the remarks groups in such a way that the responses address each question through the perspective afforded by each of the semantic domain categories. Through the lens of each category, the formulated response to each question helped identify change or what made the digital microscope lessons distinctive.

In the Findings section below, the formulated responses are organized according to research question, then by semantic domain category under each research question. Responses are organized under each category according to year (2004 or 2006) and follow a logical progression under each respective year. At the end of all the formulated responses for each research question, a summary and conclusion for each research question is presented.

The research questions are:

1. How does the introduction of the digital microscope into classrooms affect the way that the participant teachers view science and technology?

2. How does the introduction of the digital microscope into classrooms affect the way that the participant teachers teach their classes that use microscopy?

3. How does the introduction of the digital microscope into classrooms affect the way that the participant teachers view student learning using microscopy?

The summary and conclusion for each research question address the use of the digital microscope in the elementary classroom. Taken together, the summary and conclusion of all the research questions answer the main research question: *How does the introduction of the digital microscope into elementary (K-5) enrichment and art classrooms affect what teachers say and do?*

As mentioned previously, the semantic domain categories, in alphabetical order, and their definitions used throughout this study are: (1) *characteristic* (describes the digital microscope); (2) *comparison* (compares experiences and things seen); (3)

computer (relates the digital microscope's use of software, etc.); (4) *connection* (connects to science, mathematics, art, and state and national standards); (5) *knowing* (understands a concept better); (6) *object* (relates to how things look); (7) *seeing* (notices differences under different magnifications); (8) *students* (participant teacher comments about observations of students); and (9) *teacher* (participant teacher comments about self and about other teachers). For a more detailed discussion of the categories, see the Overview for the previous chapter (Chapter IV, Analysis of Data).

Findings for Teacher E and Teacher A

In the following sections for each teacher, a code is used to identify where in the interviews the question's response is based. This code appears in parenthesis at the end of the sentence or series of sentences forming the answer. For example, A4-1 means "from interview after first lesson 2004, remarks group 1" and P6-11 means "from post-interview 2006, remarks group 11." In order to help further with identification, the prefix E was added for Teacher E and a code was added to track the semantic domain category (i = characteristic; ii = comparison; iii = computer; iv = connection; v = knowing; vi = object; vii = seeing; viii = students; and ix = teacher). An example of a complete code is E-ix-P6-1, in this instance, meaning Teacher E, category teacher, post-interview 2006, remarks group 1.

Findings for Teacher E

First Research Question

How does the introduction of the digital microscope into classrooms affect the way that the participant teachers view science and technology? Responses to this question were revealed through several semantic domain categories, as described below.

Characteristic. The view of this participant teacher about science and technology, as revealed through the semantic domain category *characteristic*, included the following results. In 2006, the teacher noted that the digital microscope's capabilities were enhanced by related computer software technology (including image labeling), an effect which was not possible with the standard light microscope that had been used in some lessons in past years (E-i-P6-4). Also, students could make a movie (video) instead of a static image, which helped in some lessons (E-i-P6-4).

The teacher remarked about the many child-friendly characteristics of the digital microscope, including the fact that its software was similar to computer programs that the students knew about already. And, the teacher expressed a personal interest in the computer-related aspects of the digital microscope (E-i-P6-8). The teacher felt that the computer-related aspects of the digital microscope would help develop computer skills in the students who used them in enrichment classes (E-i-P6-8).

Comparison. The view of this teacher about science and technology, as revealed through the semantic domain category *comparison*, included the following results.

In 2004, the teacher related the digital microscope's software to computer programs that students had already used. Using this comparison, the teacher began to instruct the students about imaging using the digital microscope (E-ii-A4-2). The teacher noted that by comparison with other methods the digital microscope's technology had provided the students with a remarkable tool that they learned to use in order to see more clearly something that they could not see with the unaided eye (E-ii-A4-3).

In 2006, the teacher noted that in the past (using the standard light microscope), the teacher was never really able to know for sure if the students were seeing the correct thing or if the microscope was correctly in focus. The technology of the digital microscope overcame this problem and at the same time improved the way that students were able to view objects under magnification, both of which helped the teacher and students work together during lessons (E-ii-P6-3).

The teacher was excited about some possible comparable future applications of digital microscopy and related wireless laptop technology, which might be available to all students at some time in the future. The teacher remarked 'wow' in describing this possibility and this showed how much the teacher was impressed by the possibilities of these future applications (E-ii-P6-4).

The teacher embraced the digital microscope's capability to link to a computer so that digital images could be stored and how this allowed other uses of those images later on. For example, the teacher spoke about how the images could be downloaded later and the students could write a story about those images. Comparable methods were too time-consuming to be practical for lessons (E-ii-P6-5). The teacher remarked that the science and technology of digital microscopy crossed into other disciplinary areas, unlike other methods and tools of the past (E-ii-A6-1).

Computer. The view of this participant teacher about science and technology, as revealed through the semantic domain category *computer*, included the following results.

In 2004, these responses addressed the first research question:

(1) The teacher viewed the science and technology of computers and display monitors, in combination with digital microscopes, as being highly effective in student learning about computers and their uses (E-iii-A4-8);

(2) The teacher noted that students were able to apply what they learned in art class (i.e., using the computer with the digital microscope) to lessons in the enrichment class. This kind of scaffolding of learning about the computer was remarkable and was noted enthusiastically by the teacher (E-iii-P4-2);

(3) The teacher noted that 'launching a program' was an aspect of learning to use the computer that the teacher used to engage students when starting to use the digital microscope (E-iii-A4-6);

(4) The teacher noted that using the computer and its file-storage capacity was a way to create a folder of digital imagery that could be used later on in a subsequent study of natural and man-made objects. The teacher found this to be a very useful aspect of the computer as related to the digital microscope (E-iii-P4-3);

(5) The teacher observed students learning about computer software (related to the digital microscope) by using its 'special effects,' such as adding sound with movies, visual effects, painting and labeling; and others. The teacher had a positive view of all these 'special features,' which can applied to a digital image or a digital video that is seen using the digital microscope's software. The teacher learned about what software functions the students used in making special effects and this in turn informed the teacher about what the students were interested in doing with the computer (E-iii-P4-5). Also, this work could be saved in a students' digital folder, and the teacher viewed saving the

work as a learning mechanism, which allowed students to look at their work later and share with others (E-iii-A4-7);

(6) The teacher's comparison of the digital microscope's programs to other computer programs (i.e., Word and PowerPoint), in which the teacher already had confidence, improved the teacher's view of the technology. In addition, the teacher relied on the students' familiarity with other such computer programs to build up their knowledge of computer technology using digital microscopy. The teacher showed confidence in the experience of the students with other computer programs which transferred to confidence in students learning digital microscope computer technology (E-iii-A4-2); and

(7) The teacher noted that having the ability to use the digital microscope 'hooked up' to a laptop computer suggested to the teacher that lessons could be done successfully outdoors, which in turn showed that the teacher's lessons could potentially go beyond the walls of the present classroom in the future (E-iii-A4-3).

In 2006, the teacher remarked on how the effects of computer-based, digital microscope technology, tended to focus student attention on the topic of the lessons. The teacher viewed the computer technology of digital microscopy in a very positive way when the teacher spoke about focusing student attention in learning (E-iii-P6-1).

The teacher viewed the new computer technology as a learning aid, which the teacher employed in the enrichment classroom, the computer laboratory, and the students' homerooms. The digital microscope became a lens that provided a view to what the students thought was interesting to look at, worthy of imaging, and useful enough to save and view later. The teacher specifically described the many things that students could do and did with the saved images (E-iii-A6-1).

The teacher, who had an academic background in computer applications, showed an example to the class and from this example the students were able to apply what the teacher commented on and continued on their own. In this instance, the teacher was demonstrating how to complete a task with the digital microscope based on prior knowledge and experiences. In the teacher's view, this kind of demonstration could be successfully shared with students because of the nature of the new technology (E-iii-A6-2).

Connection. The view of this participant teacher about science and technology, as revealed through the semantic domain category *connection*, included the following results.

In 2004, the teacher viewed the enrichment activities and the technology of the computer-based, digital microscope as means to establish connections between scientific and artistic concepts. To the teacher, this was a way to have 'back and forth' learning and exploration of these fields within one activity (in this instance, the activity on crystals, which held both scientific meaning and artistic beauty) (E-iv-P4-3). In a related matter, the teacher also remarked on interdisciplinary connections that were possible with digital microscopy. The teacher noted that this applied to state standards as well (E-iv-P4-6).

Citing the digital microscopy lesson on examination of the one-dollar bill, the teacher was able to address curriculum standards. In addition, the more the teacher used the digital microscope, the more that the teacher could make connections to various curriculum standards. The teacher was excited to have some new ideas for the next year's curriculum, which emerged from using the digital microscope. Using the digital microscope gave the teacher these new views and insights (E-iv-P4-7).

In 2006, the teacher felt that digital microscopy had implications for the new technology curriculum and had applications in the mathematics curriculum as well. The teacher viewed these connections favorably in looking to the future (E-iv-P6-10). Also, the teacher became increasingly comfortable with the digital microscope and saw how it could be easily integrated into many lessons (E-iv-P6-12).

The teacher's view of science changed as noted in the teacher's remarks directed to students about the nature of science regarding digital microscopy. In the teacher's view, the students had the experience that a scientist might have looking through a microscope, which helped the students connect with science and scientists (E-iv-P-13).

The teacher noted that the digital microscope and its technology 'speeded things up' and made it easier to view objects. By this the teacher meant that students could make scientific observations faster and easier like scientists would in the real world (E-iv-P6-13).

Students. The view of this participant teacher about science and technology, as revealed through the semantic domain category *students*, included the following results.

In 2006, the teacher felt that the students were coming to the enrichment classroom with considerable knowledge of other digital technology from having used digital cameras, etc. outside of the classroom. The teacher viewed this background as positive and an aid in students' learning about digital microscopy (E-viii-A6-10).

Teacher. The view of this participant teacher about science and technology, as revealed through the semantic domain category *teacher*, included the following results.

In 2004, the teacher stated that the new technology (the digital microscope) made the teacher 'excited' and 'feel good' about using it (E-ix-P4-1).

In 2006, the teacher noted that the new digital microscope technology 'makes you learn things that the students are doing.' The teacher noted that new technology meant the teacher needs to prepare for the lessons with digital microscopy (E-ix-P6-1).

The teacher saw digital microscopy as evidence that future change in technology would be coming rapidly and this caused the teacher to think about how this change would affect the students. The teacher asked the students to think about this during the lessons (E-ix-P6-5).

The teacher found that the digital microscope technology (specifically all the computer monitors showing digital imagery) allowed the teacher to observe more what was happening at each microscope station. The teacher saw this as a significant improvement in teaching method (E-ix-P6-6).

The teacher found that the digital microscope was relatively easy to learn and this contributed to the teacher's positive feeling about this new technology (E-ix-P6-7).

The teacher was amazed at the discoveries that were made using digital microscopy. The teacher felt that it was very easy to make these discoveries with the new technology and conveyed this to the students (E-ix-P6-8).

The teacher saw digital microscopy as a solution to several problems that had plagued enrichment lessons conducted in prior years using standard light microscopes (E-ix-P6-9).

Summary for the first research question. The teacher's view of the science and technology of the digital microscope and the related computers' components and software was that their characteristics stimulated students to learn more about computer technology. In the teacher's view, this new learning built upon the students' computer backgrounds and helped enhance students' computer skills. The teacher also expressed a personal interest in learning more about the computer-related aspects of digital microscopy. By comparison, the teacher thought that the digital microscope was much more effective in lessons than the standard light microscope. For example, the teacher found that it was not possible to know if the students had the objects in focus or were seeing the correct thing when using the standard light microscope. In digital microscopy, these problems were solved. The teacher suggested that the laptop-digital microscope configuration could be taken outside for nature lessons. The teacher was impressed with the ability to store and later download digital images from student enrichment lessons. The teacher spoke about the computer with regard to digital microscopy saying that students now could learn about these things in art class and then could bring their knowledge to enrichment class, which was good. The computer's capabilities for file storage, generating special effects (such as labeling and visual enhancements using digital microscope software), and its ability to strongly focus student attention were all noted by the teacher. Connections of the digital microscope included the artist-scientist connection, which emerged from the teacher's enrichment lessons such as the study of crystal growth. The teacher mentioned 'back and forth' learning to express the making of connections by students as they worked on enrichment lessons using digital microscopy. The teacher felt that interdisciplinary connections and connections with state standards were formed using the digital microscope. Curriculum ideas emerged in this process; for example, in the enrichment lessons on one-dollar bills, connections to history emerged. The teacher mentioned that the digital microscope would connect with new state technology standards in the future. The teacher noted that the digital microscope put students in touch with how it felt to do science and be a scientist. The teacher noted that students came to the class with experience using digital cameras, so they readily adapted to the digital microscope. The teacher commented that the digital microscope was 'easy to learn' and that the teacher 'felt good' and was 'excited' about using the new digital microscope. The teacher also remarked that using it 'makes you learn things that the students are doing.' The teacher mentioned that being able to see all the computer monitors at the same time was a great improvement in effective instruction that is associated with the digital microscope.

Conclusion for the first research question. The new technological tool (the digital microscope) and related computer components, including the file-storage capability of the computer software and the visual effects software of the digital microscope, affected the teacher's view of teaching lessons with this equipment in a positive way and there was the potential for long-term change in instruction of some enrichment lessons. In addition, the new digital microscope technology might be part of the new technology curriculum that would come to the elementary school in the near future.

Second Research Question

How does the introduction of the digital microscope into classrooms affect the way that the participant teachers teach their classes that use digital microscopy? Responses to this question were revealed through several semantic domain categories, as described below.

Characteristic. The view of this teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *characteristic*, included the following results.

In 2004, the teacher expressed confidence in the physical attributes of the microscope technology (child-friendly as well as sturdy and inexpensive so that the teacher was not worried about the cost if a student broke one). The teacher's confidence and lack of worry provided an environment for the students to freely use the new technology to explore and observe, which was different from using the standard light microscope (E-i-P4-1).

The teacher found that in using the digital microscope technology, especially the hand-held mode, the students preferred to look at things that interested them and they became engrossed in the lesson. This was not anticipated by the teacher initially and these things emerged as the lesson evolved. The lesson became driven by student interests and the objects provided for the enrichment lesson. Observing these lessons informed the teacher about what things interested students (E-i-P4-1).

In 2006, these responses addressed the second research question:

(1) The teacher found that in using the digital microscope 'everybody could see everything all at once' because the computer monitors connected to the digital microscopes. The teacher felt more confident ('safer') about student learning during the enrichment lessons because all students (and the teacher) saw the digital images simultaneously. The teacher found this preferable to the alternative method of students' taking turns looking at objects (i.e., using the standard light microscope) (E-i-P6-3; P6-7);

(2) The teacher found that the students needed time to explore the characteristics of the digital microscope. The teacher found that the lessons needed to have a component of time for this student exploration. This represented a change in the teacher's views about the importance of including more time for student exploration (E-i-P6-4);

(3) The teacher noted that the teacher changed lesson plans for some lessons in order to incorporate digital microscope technology in the new lessons (E-i-P6-5);

(4) The teacher noted the digital microscope's characteristics enhanced and developed the students' computer skills through the digital microscope's software and computer connections (E-i-P6-8);

(5) The teacher remarked about wanting to add more ways to use the digital microscope's features (such as digital video, digital image labeling, and special effects) in other lessons and then compared them with lessons using the digital microscope in previous years (E-i-P6-9);

(6) The teacher mentioned the digital microscope's characteristics in saying what students did in order to see an object more closely and described this in specific detail. This revealed a change in the teacher's scientific knowledge of digital microscopy. Also, there was a change in the level of knowledge of the teacher in understanding what the students were doing and thinking during specific digital microscope activities (E-i-P6-11);

(7) The teacher found the digital microscope's capability to make digital images and the computer-software capability to store images were very important in lessons. The teacher incorporated the software capability to save many different images

made by students, which then could be retrieved later and used in other lessons, in the lesson plan for activities (E-i-A6-2); and

(8) The teacher continued to have confidence in the safety of the equipment and its low cost (E-i-A6-1).

Computer. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *computer*, included the following results.

In 2004, these responses addressed the second research question:

(1) The teacher noted that students applied what they learned about computers and the digital microscope in art class to enrichment lessons and the teacher considered how to build on that previously acquired knowledge of computers (E-iii-P4-2);

(2) The teacher had confidence using the digital microscope because of pre-existing computer skills that the teacher possessed. The teacher's confidence was transferred to the students. The teacher asked students to consider the computer programs they had worked with previously and noticed how similar the digital microscope's programs were to those programs (E-iii-A4-2);

(3) Because of the laptop computer, the teacher was open to going outside the classroom with digital microscopy, a change in environment that would open up other opportunities for lessons that were not possible previously (i.e., using the standard light microscope) (E-iii-A4-3);

(4) The teacher wanted the students to master the computer aspects of digital microscopy and then see it as a science tool that had features like a movie or video

camera. The teacher explained the differences between a movie or video camera and the digital microscope as the students began working with it (E-iii-A4-4);

(5) The teacher encouraged the students to use the digital microscope's computer software to achieve visual effects, add sound, make videos, and save work to their digital folders. This kind of student activity during enrichment lessons was not possible previously using the standard light microscope or hand lens. In the past, once the student left the microscope that visual image could not be saved or shared in any way with other students or the teacher. There was no way to manipulate, record, or store images for later viewing (E-iii-A4-7);

(6) The teacher found that the computer monitors and the central big screen permitted all students to view all digital images at the same time. This effect was important in the interactive nature of the lessons employing digital microscopy. This computer-based interactive capability was viewed as very important to student learning. Previously, each student could only view microscopic scenes on an individual basis and thereafter they discussed what they saw, but discussing a common view of the lesson was not possible (E-iii-A4-8).

In 2006, the teacher noted that installing the digital microscope's software program by using the compact disc (CD) and saving the program to avoid having to use the CD in the future was important to this teacher. The teacher had prior knowledge in this area, which helped reduce class time spent on this matter (E-ii-A6-1). Also, the teacher showed the students an example of the type of digital images needed for the lessons and the students were able to apply what the teacher stated and continue on their own. The teacher showed proficiency with the digital microscope applications, and this put the students at ease (E-iii-A6-2).

Connection. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *connection,* included the following results.

In 2004, these responses addressed the second research question:

(1) The teacher acquired a different perspective of science lessons by using digital microscopy, specifically; the teacher became aware of the connection to math and the study of shapes or geometry (E-iv-P4-1);

(2) The teacher recognized the art connection and changed one of the lessons so that students could engage in artistic exploration of natural materials. This allowed the students to express themselves in an artistic way. The teacher came to recognize that students were naturally artistic as well as scientific in their explorations using digital microscopy (E-iv-P4-2);

(3) The teacher found that allowing students to manipulate crystals and study their shapes during the science lesson on crystals caused students to make a connection and 'go back and forth' from science to math to art and back to science. The teacher noted that the digital microscope made exploration of these connections possible (E-iv-P4-3);

(4) The teacher was aware of previous experiences of the students using digital microscopy in art lessons and wanted to make a connection with those experiences. The teacher was able to use the students' prior knowledge to build new knowledge during the enrichment lessons. The teacher encouraged the art-science

connection via the digital microscope (E-iv-P4-4). The teacher mentioned ways of integrating digital microscopy into some art lessons even though art was not in a significant part of the elementary enrichment program (E-iv-A4-1);

(5) The teacher noted that measuring objects or parts of objects under the digital microscope might be a way to introduce students to mathematical concepts during a science lesson. Also, the teacher spoke about mathematics and science and science and art ‘flowing back and forth.’ The teacher was thinking of connections that the teacher had observed but was also looking to the future of digital microscopy in the elementary school (E-iv-P4-5);

(6) The teacher considered how the digital microscope might help with interdisciplinary connections and in fulfilling state standards in different areas (E-iv-P4-6); and

(7) The teacher used digital microscopy for enrichment lessons on the concepts of enlargement and counting of objects that were too small to be counted with the unaided eye. The teacher progressed from giving the lessons to learning from the lessons. The more the teacher learned, the more the lesson evolved (E-iv-P4-7).

In 2006, these responses addressed the second research question:

(1) The teacher noted a connection between digital microscopy and language skills in enrichment lessons and began to include language skills (and writing) in some enrichment lessons using the digital microscope. Students used the digital microscope’s software capabilities to label their own images, which employed their language skills (E-iv-P6-2);

(2) The teacher connected multiple curriculum areas within an enrichment science lesson, which had the effect of 'compacting curriculum areas together.' The teacher found that the teacher could use these 'compacted' lessons in order to include more state standards (E-iv-P6-3);

(3) The teacher found that what was learned in enrichment class about computers and digital microscopy connected with other classes that the students were taking, which was an unexpected effect (E-iv-P6-4);

(4) The teacher noted that prior learning about computers, digital microscopes, and related technology had an effect on student's cognitive development during enrichment lessons. This affected the teacher's approach to digital microscopy lessons because the teacher wanted to make those connections (E-iv-P6-5);

(5) The teacher used the digital microscope to conduct authentic science lessons, where the discovery aspect of learning was emphasized. Student discoveries emerged as the lesson moved forward and this allowed the student to learn by exploring. The teacher encouraged a connection between discourse, discovery, and hands-on participation in digital microscopy lessons (E-iv-P6-6);

(6) The teacher brought history and social studies connections into the enrichment science lessons using digital microscopy. And, the teacher found new ways to address state standards and make interdisciplinary connections, which influenced future lessons. The teacher made many speculative connections with digital microscopy while doing lessons on studying currency and its many facets. The teacher discussed with students the many intricacies of the currency they were observing. The change here was that the teacher was discovering with students in the discovery process (E-iv-P6-7);

(7) The teacher mentioned that there was a ‘give and take’ during the lesson as a result of students asking ‘why’ and the teacher saying ‘we have to look it up.’ This showed how the teacher relied on looking in reference materials and on-line sources, which were connected with the digital microscopy lesson. The teacher encouraged the students to ‘look up things’ that they did not understand after looking at those things first using digital microscopy. Also, the teacher used the digital microscope in a way so as to encourage students to conduct personal research on a topic they were studying. This teacher’s method promoted research at the same time that students had their interests piqued and had burning questions about things they just discovered using the microscope (E-iv-P6-8);

(8) The teacher saw digital microscopy as a way to connect with curriculum issues in technology, science, and mathematics (E-iv-P6-9). The teacher began to see other potential connections for present and future lessons as well (E-iv-P6-10; P6-18);

(9) The teacher observed that students ‘bloomed’ as they used digital microscopy; therefore the teacher planned further use of the digital microscope and planned connections with new and different lessons in the future (E-iv-P6-11);

(10) The teacher felt that the digital microscope could be used to connect to students’ natural curiosity and desire for inquiry by making a special ‘center’ in the classroom for students where students could use the digital microscope even while the teacher was teaching a lesson on something else. The teacher ‘felt comfortable enough’ with the digital microscope to have this separate student ‘study center’ within the classroom (E-iv-P6-12);

(11) The teacher viewed the digital microscope as a way to help connect students with the nature of science and to make a connection to science for all students using the equipment (E-iv-P6-13);

(12) The teacher had limited physical storage space, so space needed to be taken into consideration in lesson planning. With digital microscopy, there was a connection to space limitations. The teacher felt that it was possible to devise new enrichment lessons that caused the curriculum to continually evolve yet did not continue to add volume to the teaching collections housed in the classroom (E-iv-P6-14);

(13) The teacher wanted to connect with the study of change. The teacher moved from looking at static objects to having students study change under the digital microscope. The teacher wanted the student to be aware of changes, for example, that occurred as crystals grew within a liquid. This kind of enrichment lesson was made possible by using the digital microscope's video capability, which allowed the students to see and replay a process such as crystal formation (E-iv-P6-15);

(14) The teacher saw the value in talking about ethical issues, which was an unexpected connection that emerged when using the digital microscope. The teacher discussed the intellectual property concept as the students were making digital images and labeling some of their favorite images (E-iv-P6-16); and

(15) The teacher felt that an Internet connection to digital microscopy sites, whether an external or internal site, would be helpful for student learning, both inside and outside of class. The teacher wanted to create a class web-page for this purpose (E-iv-P6-17). The teacher wanted the students to find Internet sites where they could compare digital images to the ones they were making in their enrichment lessons. The teacher

wanted students to make an external connection (E-iv-A6-1). And, the teacher wanted to allow the students to be able to gain access to appropriate web-sites not only in school but also at home. The teacher felt that student learning while doing digital microscopy lessons would be enhanced by Internet-based inquiry (E-iv-A6-2).

Object. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *object*, included the following results.

In 2004, these responses addressed the second research question:

(1) The teacher noted that during student lessons using digital microscopy, the students more quickly learned the lesson when they were allowed to examine objects that they found, that interested them, and that held their attention (E-vi-P4-2);

(2) The teacher noted that enrichment lessons became student-driven inquiry lessons when students were allowed to investigate objects that interested them and to discuss their findings with other students. This created a learning community where students were actively discovering and communicating their findings about various objects across the classroom (E-vi-P4-3);

(3) The teacher noted that the students understood the difference between the object being studied and its magnified image provided by digital microscopy. Having this understanding among students allowed the teacher to move forward with planned lessons in digital microscopy (E-vi-P4-4);

(4) The teacher felt that many different objects could be brought into the digital microscope lessons, including fruit flies and other insects, currency and coins

(‘money’), plants, and other objects. The teacher was open to student inquiry about all such things using digital microscopy (E-vi-P4-5);

(5) The teacher noted that observing crystals growing was the sort of enrichment inquiry lesson that could be accomplished well using digital microscopy (E-vi-A4-1);

(6) The teacher was willing to change the focus of the lesson to objects that the students were particularly interested in seeing (in this instance, other students’ skin and hair) in order to capture student attention, interest, and imagination. This allowed the students to relate digital microscopy to themselves first. The teacher encouraged students to conduct their own inquiry during enrichment lessons using especially the hand-held mode of the digital microscope (E-vi-A4-2);

(7) The teacher gave students U.S. coins as objects for study and asked them to observe their surfaces. The many observations and questions about what students were seeing on the coins prompted additional inquiry on the part of the students. The teacher gave the students these objects to study, but then the students made observations on those objects and these observations subsequently became the driving force in inquiry (E-vi-A4-3); and

(8) The teacher gave the students an object, in this instance a doily, and asked them to examine the finer details of the structure of the doily. The students noted these finer details as part of their lesson (E-vi-A4-4).

In 2006, these responses addressed the second research question:

(1) The teacher conducted inquiry-based lessons by allowing students to look at objects that especially interested them. In this instance, the human eye was of interest

to the students and the teacher encouraged them to study it (safely) using the hand-held mode of the digital microscope. The teacher encouraged discourse among students on what they were seeing during such lessons (E-vi-P6-1);

(2) By allowing students to study what they wanted to during the lessons, the teacher also encouraged social interaction among students as they observed each others' skin and hair using the digital microscope. The teacher allowed the students to conduct their own inquiry using the digital microscope and they chose objects that interested them as the focus of their investigations (E-vi-P6-2);

(3) The teacher permitted students to pursue their own interests in looking at the small-scale features on U.S. currency. The students were fascinated by what they saw and this helped drive the inquiry lesson (E-vi-P6-3);

(4) The teacher encouraged students to bring things from home (in this instance, currency from other countries) to examine as part of their inquiry-based lesson on digital microscopy. The teacher saw that there was a connection to other disciplinary areas, including social studies and history, through these objects. In this process, the teacher encouraged students to examine this connection (E-vi-P6-4);

(5) The teacher encouraged the students to take a close look at the composition of a common object (in this instance, U.S. currency) and determine what it was. The teacher structured this inquiry so that the students discovered for themselves that the object had a different composition than what the students expected. The teacher used this inquiry to allow students to discover that looking closer may reveal a different composition than one originally expected. When the students found that the currency was not paper, this was a type of 'discrepant event' in the lesson. The teacher shared in the

excitement of discovery of new things as the students looked closely at U.S. currency. The teacher encouraged students to make these discoveries by using the digital microscope (E-vi-P6-5);

(6) The teacher presented students with some objects for inquiry (in this instance, U.S. currency) and the students began to observe and draw connections between artistic designs that they had seen before and the designs on the currency. The teacher encouraged the students to make connections to their prior knowledge of art. The students conducted further inquiry in to the nature and origin of the designs they saw, for example, history behind the *fleur de lis* on the U.S. currency (E-vi-P6-6);

(7) The teacher used the students' fascination with U.S. currency as a way to encourage their inquiry into the microscopic world of printing on currency. The teacher used digital microscopy in the enrichment lesson and asked students to describe what they saw. This led to emerging inquiry by the students because the printed detail of the currency was very complex as was the actual structure of the bill itself (E-vi-P6-7);

(8) The teacher's interest in crystal growth from previous lessons was a factor in the teacher's decision to use digital microscopy in new lessons (E-vi-P6-9);

(9) The teacher provided some objects (in this instance, coins and currency) for examination. The students informed the teacher that this was their favorite activity and this information encouraged the teacher to use the activity in the future (E-vi-A6-1);

(10) The teacher explained that the students brought in butterflies (and 'parts of butterflies') from home for examination during one of the enrichment lessons using digital microscopy. The students were fascinated by these objects (butterflies) and their curiosity was the force that drove the lesson (E-vi-A6-2);

(11) The teacher felt that hands-on learning and manipulation was essential for an effective enrichment lesson and that digital microscopy was a very effective means of hands-on learning (E-vi-A6-3); and

(12) The digital microscope lessons taught by the teacher not only to encourage students to look more closely at objects and to understand them better and also to make connections from those objects to other areas such as art, history, social studies, and mathematics (E-vi-A6-4).

Seeing. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *seeing*, included the following results.

In 2004, these responses addressed the second research question:

(1) The teacher gave the students a coin and asked them to observe it using the digital microscope and to see for themselves what the markings on the surface of the coin meant. The students were fascinated that they could interpret the meanings of the markings and the teacher allowed this fascination to drive the lesson forward. The teacher felt that student-driven inquiry such as this was very effective in student learning (E-vii-P4-1). The teacher encouraged students to engage in discourse about the marks on the coins and to better understand the origin of the many surface features they observed (E-vii-P4-2);

(2) The teacher allowed students to examine the functions of the digital microscope and use them in the inquiry classroom in order to see objects in a new way. Students discovered that the hand-held mode of the digital microscope allowed them to see many things much better and they communicated this within the classroom

community. The teacher observed what was happening and allowed using the hand-held mode to become part of the enrichment lesson (E-vii-P4-3);

(3) The teacher asked students to bring in objects for study from outside the classroom. Seeing these objects in a new way with magnification piqued student interest and contributed to the students' sense of ownership of the lesson. Again, the teacher permitted student curiosity and interest to drive the lesson (E-vii-P4-4);

(4) The teacher participated in the student inquiry and listened as the students engaged in observation and discourse about what they were seeing and how they were seeing. In this instance, the students investigated the concept of natural versus man-made properties of selected items and they discussed and then drew conclusions as they went along. The teacher encouraged this interaction as part of the lesson (E-vii-P4-5). The lesson was allowed to evolve with the student interest (E-vii-A4-3);

(5) The teacher encouraged students to see connections between things they observed using digital microscopy and their experiences in the natural world in order to gain understanding. In this instance, some students observed a bee's stinger using the digital microscope and saw why the stinger hurt when it touched the skin. The teacher participated in the inquiry and encouraged students to engage in discourse about their findings (E-vii-P4-6);

(6) The teacher encouraged students to work with the digital microscope and as a result some students experienced a moment of discovery, or the 'aha moment' as they better understood a concept or relationship. The teacher encouraged students to explore using digital microscopy and to bring in their prior experiences with the things being studied in helping to understand and interpret what they were seeing (E-vii-P4-7);

(7) The teacher found that students used simple language, especially at first, in order to describe what they were seeing and discovering during the lesson using digital microscopy. As their seeing and understanding evolved, the teacher discovered the students using more scientific terminology (E-vii-P4-8; A4-4);

(8) The teacher allowed students to select from things already in the classroom and to bring things from outside the classroom in order to conduct inquiry lessons on what the students wanted to study using digital microscopy. The teacher found that this was successful and that the students commonly expressed their curiosity by saying ‘what about this?’ and then moving to the digital microscope to take a look (E-vii-A4-2);

(9) The teacher asked students to *see* a coin – look closely enough at a coin in order to answer a simple question, in this instance, what do the imprinted words and symbols mean? In this lesson, the teacher used the ‘surprise factor’ of discovery to help engage students during the lesson’s inquiry process (E-vii-A4-5); and

(10) The teacher encouraged the students to handle and manipulate the objects being studied before looking at them with digital microscopy. The teacher felt that this touching (haptic perception) made the objects more easily understood to students when they were magnified (E-vii-A4-6).

In 2006, the teacher continued to act as a partner in the inquiry process using digital microscopy. The teacher encouraged students to *see* or look more closely for features that might have been missed at lower magnification and to make note of those things during the lessons. The teacher encouraged students to see the hidden world by exploring it for themselves (E-vii-P6-1).

In this lesson on currency, the students explored in detail the things that particularly interested them. The teacher permitted students to explore based on their own interests, which were part of the lesson (E-vii-P6-2).

The teacher found that some students had different perceptions and saw the digital microscope images in different ways. Also, the teacher noted that students were less likely to understand what they were seeing in the digital microscopy inquiry as the magnification was increased. The experience and perception of the students at low power did not typically carry over to higher magnifications. The teacher felt that this limitation on seeing should continually be taken into account (E-vii-A6-1).

The teacher allowed the students to gain the needed skill and perception in seeing even though the microscopes might be bumped or knocked out of focus. The teacher viewed this as part of the lesson in digital microscopy (E-vii-A6-2).

Students. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *students*, included the following results.

In 2004, these responses addressed the second research question:

(1) The students worked primarily in pairs, which worked well according to the teacher because one student might see something or make an observation that led to a better understanding through collaboration (E-viii-P4-1);

(2) According to the teacher, the students liked insects, which increased student interest in the lessons on insects using digital microscopy. Also, the teacher noted that digital microscopes themselves tended to attract the attention and participation of

students. The lessons became more inquiry-based as a result of the students' increased interest (E-viii-P4-2);

(3) The students were engaged by the 'fun' and enjoyment aspect of using digital microscopy in enrichment lessons (E-viii-P4-3) and the teacher found that students' excitement carried over into a desire to take images and discoveries home to share with parents (E-viii-A4-4);

(4) The teacher noted that the students' experience with digital microscopy (and how it changed their view of science) fostered continued interest on the part of the students in doing inquiry using digital microscopy. Also, the teacher engaged student excitement and inquisitiveness in helping students become more interested in digital microscopy (E-viii-P4-4);

(5) The teacher found that students liked to 'experiment' or select for themselves what they wanted to study and focus on with digital microscopy. And, the students liked to bring in materials from outside the classroom, which helped maintain student interest in the lessons (E-viii-A4-2). The teacher noted that the students naturally learned from one another in the inquiry classroom (E-viii-A4-1);

(6) The teacher found that students could function like scientists if their inquiry was allowed to go forward according to the way they want to study the materials. The teacher felt comfortable allowing the inquiry to be student-driven in this way (E-viii-A4-3);

(7) The teacher found that it was important for the students to study and observe the object for a time before making a digital image of the object. From the saved digital image, the students could print out copies at different enlargement scales. The

student also had archived images to compare different magnifications during lessons (E-viii-P4-3).

In 2006, these responses addressed the second research question:

(1) Some students saw things differently under the digital microscope and some did not recognize what they were observing. However, the teacher noted that through social discourse these discrepancies were resolved and the students progressed and learned from each lesson (E-viii-P6-1);

(2) The students' natural curiosity drove the lessons using digital microscopy, which started out as typical enrichment lessons but evolved into more inquiry-based lessons as well (E-viii-P6-2). The teacher encouraged students to think about digital microscopy versus other experiences they had with hand lenses and standard light microscopes, and the students preferred digital microscopy (E-viii-P6-3; P6-4);

(3) Because of the computer monitors, the teacher directed students from a vantage point in the classroom where the teacher could see and hear what all students were doing and discussing. Student discourse and gesturing during inquiry promoted student learning using digital microscopy (E-viii-P6-5);

(4) Students made discoveries that changed the course of the enrichment lessons and took them in new directions. Student discourse was the driving factor in changing direction of the enrichment lessons (E-viii-P6-6). The teacher partnered with the students during these lessons and this formed an effective inquiry-based structure for the lessons (E-viii-P6-7);

(5) The students told the teacher that they would like for each student to have their own digital microscope (E-viii-P6-9). However, not having enough digital

microscopes for each student to have one alone all the time, the teacher found that it was best to have two students per digital microscope in order to facilitate inquiry and so that students could fully participate (E-viii-A6-11; A6-12);

(6) When asked to view movement or change using the digital microscope, the students tended to move static objects while under the digital microscope rather than seeking out objects that moved or changed (e.g., living things or growing crystals) (E-viii-P6-8);

(7) Students sometimes were intrigued by things that they were seeing, for example, saying that the object seemed ‘magical’ or ‘tricky.’ The teacher learned of these feelings among some students and noted that this curiosity motivated them to use the digital microscope (E-viii-P6-15);

(8) The students’ sense of ownership of the digital microscopes was evident in many lessons and was viewed by the teacher as a positive sign about the lessons at hand (E-viii-P6-16). The student enthusiasm for the digital microscope inquiry (including the desire of some students to bring out the digital microscopes for additional research when the class was on another topic) was another way that students expressed interest in ownership of the equipment and their discoveries (E-viii-P6-18);

(9) The students were encouraged to take the time to look closely at what they were seeing and not be so quick to interpret the images (E-viii-P6-19). The teacher commented to students ‘you know you are right’ and ‘where have you seen this before,’ hoping they would connect with prior knowledge during inquiry using digital microscopy (E-viii-P6-20);

(10) Students gained a greater understanding of objects by handling and manipulating them versus seeing them statically on the Internet (or on a shelf in the classroom). The teacher noticed how the students handled various objects and encouraged them to do so as part of the lessons (E-viii-P6-21);

(11) The students expressed to the teacher that was important for them to feel that they were doing something *new* and not repeating older inquiry lessons (E-viii-P6-27);

(12) Students who might not normally be engaged fully in the classroom were brought into the activity using digital microscopy (E-viii-A6-1). Students worked together better when using digital microscopy and students who would not normally work together did so sharing a digital microscope (E-viii-A6-3). Also, students were more willing to try new approaches to seeing with the digital microscope and they learned from one another by mutual discourse and gesturing during the lessons (E-viii-A6-2);

(13) The students made connections between experiences during inquiry and experiences in other parts of the curriculum if allowed to do so. The teacher encouraged these connections, which seemed to come naturally to the students while using digital microscopy (E-viii-A6-6);

(14) The students exhibited a sense of excitement and accomplishment among themselves, and they wanted to save their work (an indication of the sense of ownership in their work) (E-viii-A6-7); and

(15) The students thought of themselves as young scientists while using the digital microscopes, and the teacher felt this had a positive effect of the lessons (E-viii-A6-13).

Teacher. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *teacher*, included the following results.

In 2004, the teacher was excited and confident about digital microscopy and this was conveyed to the teacher's students (E-ix-A4-1). Also, the teacher thought that it was important to watch other teachers coming up with new ideas regarding inquiry lessons in digital microscopy (E-ix-P4-1).

The teacher used the digital microscopes in enrichment lessons where the outcomes of the lessons were not known. This allowed freedom of student inquiry and was an effective way of teaching the digital microscope lessons in the teacher's view (E-ix-A4-1; A4-3).

The teacher noted that the students were encouraged to look at object after object and study them thoroughly using the digital microscope in order to understand the objects and the process of microscopic investigations. In this way, the teacher permitted students to do student-driven inquiry in the classroom (E-ix-A4-3).

The teacher noted that when students came to the class with some background knowledge in technology, the students learned more during the lessons (E-ix-P4-1). This view, which was reinforced by the teacher's experiences during digital microscope lessons, affected the way that the teacher instructed the class (E-ix-A4-2).

The teacher saw how the classroom could potentially be 'without walls' and connected to the outdoors using digital microscopes and laptop computers (E-ix-A4-1) and the teacher noted that future applications of digital microscopy and wireless laptop technology were exciting (E-ix-P6-4);

In 2006, these responses addressed the second research question:

(1) The teacher found it necessary to learn about digital microscopy at the same time as the students. In the teacher's view, this was a positive aspect of the new technology (E-ix-P6-1). The teacher used the digital microscope in advance of the class lessons in order to understand its functions and communicate these to the students. Also, the teacher wanted to feel confident with the digital microscope so that the students felt confident with it (E-ix-P6-7; A6-1). By working with the microscope personally, the teacher gained a new personal appreciation for the hidden microscopic world and this interest carried over into the teacher's lessons about digital microscope lessons (E-ix-P6-2);

(2) The teacher used an on-going project as a way to start students using the digital microscope in enrichment class. The teacher asked students to observe parts of plants that they were growing already as part of a separate class activity (E-ix-P6-10);

(3) The teacher felt that the lessons went well when the students enjoyed what they were doing and the work that they produced looked professional (E-ix-P6-2). And, the teacher used the graphics capability of the digital microscope's software to capture and print out students artistic images for use in the posters and reports on their lessons (E-ix-P6-26);

(4) The teacher noted that by allowing the students to look at what interested them, the teacher was informed about students looking more closely at objects (E-ix-P6-1). The teacher was informed about how students see closer by their interests, which were the driving force behind the lessons. Students were interested in looking closer and closer

at things like skin and hair because they had a natural fascination with those things (E-ix-P6-2).

(5) The teacher at first tried to structure the lessons by giving students objects to look at using digital microscopy, but later learned that the students were more inquisitive about objects that they brought in to look at during the lessons. The teacher changed the lessons to allow students to bring in more of their own things to observe (E-ix-P6-3). And, the teacher listened to the students and adapted the lessons so that they could observe things that interested them and in this way the lessons evolved (E-ix-P6-4);

(6) The teacher asked the students to consider the changes in technology represented by the digital microscope and think about the future when technology would change even more (E-ix-P6-5);

(7) The teacher allowed students to do their own focusing and moving of objects, which was not as feasible when students did not see the images on a computer monitor (as in light microscopy). The teacher listened to what the students were communicating to the teacher by what they said and did, which improved the lesson's effectiveness (E-ix-P6-6);

(8) The teacher made a personal discovery about how crystals formed from a liquid and planned to share that discovery with the students during the same activity in class. The teacher hoped to convey the excitement of the discovery to the students (E-ix-P6-8). During the lesson on crystals, the teacher became a partner with the students;

(9) The teacher used the capabilities of the digital microscope's software to store and label images as a way to keep the lesson organized (E-ix-P6-9). The teacher also learned to manage large number of digital files being generated by the teacher and

students during lessons using the digital microscope. The teacher conveyed these things to the students during the new lessons (E-ix-A6-2);

(10) The teacher formed a partnership with the students in learning about digital microscopy and in working through the inquiry process of most of the enrichment lessons (E-ix-A6-4). The teacher felt that a beneficial partnership should develop between the teacher and students regarding digital microscope lessons that required students to use the digital microscope (E-ix-A6-5). In addition, the teacher listened, watched the students, and asked questions along with the students and therefore was informed by the students about the lessons and how they were doing (E-ix-A6-4; A6-10);

(11) The teacher found that students worked well in student-driven lessons, probably because the teacher would have felt comfortable with such lessons if the teacher were a student (E-ix-A6-6). The teacher encouraged the students to be creative and artistic because the digital microscope's functions allowed them to do so easily (E-ix-A6-9);

(12) The teacher thought that using the digital microscope for inquiry lessons would bring out the interconnections of many disciplines and brought this up with students as the opportunity permitted (E-ix-A6-7). The teacher felt that students could do so much more with the digital microscope and the teacher thought about other parts of the curriculum where it could be used (E-ix-A6-3);

(13) The teacher was able to see all the computer monitors from one point in the room; therefore student progress could be more efficiently seen in that way. The teacher felt comfortable supervising lessons in this new way (E-ix-A6-8);

(14) The teacher collaborated with other teachers regarding the classroom curriculum. The teacher wanted to integrate the digital technology in an interdisciplinary way and help support what other teachers were doing in their classrooms. The teacher initiated collaboration and communication among teachers, and there was additional lesson enhancement (E-ix-P6-5);

(15) The teacher changed the personal view of curriculum development related to digital microscopy based on success using the digital microscope (E-ix-P6-9). The teacher wanted more digital microscopes for the elementary school (E-ix-P6-10);

(16) The teacher's knowledge of the digital microscope's functions and levels of magnification increased substantially over time and the teacher used terminology that was much more specific to digital microscopy. In other words, there was the emergence of more scientific language in the teacher's remarks (E-ix-A6-3);

(17) The teacher employed the computer's capability to store digital images of students' work in making the teacher's lesson plans regarding digital microscope lessons (E-ix-P6-2). The teacher noted how important it was to store digital microscope images for future activities. Also, the teacher expressed the view that students could eventually work at home with things they saw during the day using a digital microscope at school (E-ix-P6-5);

(18) The teacher envisioned a lesson that crossed into several areas of the curriculum, areas that were usually taught separately. This new curriculum and lesson planning were made possible because of the versatility of digital microscope technology, which could reinforce learning across discipline areas. The teacher spoke about planning for and including digital microscopy in future lessons and in elementary curriculum

planning. Collaboration with other teachers was foreseen by the teacher. Finally, the teacher saw the bridge to art in the science applications of digital microscopy (E-ix-A6-1);

(19) In one instance, the teacher made the connection to personal hygiene (students' hand washing) and asked the students to observe their hands using digital microscopy (E-ix-P6-11). In lessons like this, the teacher used student interest in, curiosity about, and fascination with common objects to engage their inquiry about those objects under magnification and encourage the students to examine these objects closely using digital microscopy (E-ix-P6-12; P6-13; P6-14);

(20) The teacher found that the digital microscopes were of longer term interest to students than expected and that more new areas of the curriculum could be addressed using the digital microscopes than expected. The teacher used these unexpected connections of digital microscope to engage other teachers' interest in using the digital microscope (E-ix-P6-17);

(21) In one instance, the teacher encouraged students to think about their experiences using the digital microscope with various objects and asked what they could remember about whether the object was opaque or not (E-ix-P6-23). In this way, the teacher used the light that passed through an object (in this instance, some U.S. currency) to show students what was meant by not being opaque (E-ix-P6-22). Also, the teacher used digital microscopy to encourage students to re-examine their visual classification of objects, for example, opaque versus transparent or natural versus man-made (E-ix-P6-25);

(22) The teacher recognized the interactive nature of the digital microscope's technology and saw how it promoted social interaction (discourse) and learning in the classroom community (E-ix-P6-24). Also, the teacher engaged the students' sense of amazement about their findings, their sense of ownership of their results, and their desire for discourse about their discoveries as factors that helped drive the success of the digital microscope inquiry lessons (E-ix-A6-5);

(23) The teacher used the students' sense of ownership and their interest in digital imagery as an inspiring form of communication to help drive the inquiry lesson (E-ix-A6-9). And, the teacher encouraged students to continue their inquiry by allowing their sense of excitement about discovery to help motivate them to learn (E-ix-A6-8);

(24) The teacher engaged the students' prior knowledge of other digital technology (digital cameras, for example) and computer programs (Word and PowerPoint, for example) in their work in the present digital microscope lessons (E-ix-A6-10).

Summary for the second research question. The participant teacher's way of teaching enrichment classes using digital microscopy was affected by the digital microscope's *characteristics*, which were child-friendly and encouraged individual exploration and inquiry, practical (inexpensive and sturdy), engrossing for the students, and which worked well for enrichment activities (where inquiry emerged from working with this equipment). The digital microscope's capabilities made the teacher feel confident and safer using it. The digital microscope and related computer monitors permitted all students and the teacher at specific times to see everything all at once during lessons, which aided both student understanding and the teacher's ability to lead the lessons. Features such as digital imagery, digital video, file storage, and special effects (including labeling) were employed with success in the lessons.

Regarding the *computer*, the teacher noted that students built on prior knowledge of computer programs and digital devices like cameras to help acquire knowledge of the digital microscope. Using the computer helped to build teacher and student confidence. The computer aspect made digital microscopy the remarkably different technology that it is. The teacher envisioned the day when the class would go outside for activities with digital microscopy and the laptop computer.

Connections with digital microscopy noted by the teacher included science-art, mathematics (counting and measuring), language arts (labeling and describing digital images), history and social studies, and ethics. The teacher noted that curricular areas 'flow back and forth,' and different subjects were 'compacted together' by digital microscopy. With the digital microscope the teacher conducted authentic science lessons and explored the nature of science with students. The digital microscope connected students with inquiry promoting 'give and take' during lessons and prompting the students to ask 'why' (and the teacher to say 'look it up' in a reference book or on the Internet). The teacher commented that the students 'bloomed' using the digital microscope and that it connected with their natural curiosity.

While studying *objects*, students were most interested in objects that *they* selected for study. At first, students were intrigued by their eyes, hair, and skin and tended to focus on themselves, but soon they were ready for other things, including insects (flies and butterflies), money (coins and currency), crystals, plants, and man-made things like a doily. The story to be found on the surface markings on coins and the printing on currency especially interested students and led them into inquiry about how those features developed. The relationship of microscopic details on currency to subjects like history, art, and social studies came naturally to the students during the lessons. In studying objects and their microscopic characteristics, students learned that observing could lead to understandings about origins and connections to other curriculum areas. Learning by discrepant events, or learning from encountering the unexpected, was a common thing during digital microscope lessons because so much of the microscopic world was unexpected to the students. The students saw the distinction between objects and magnified images of objects for themselves.

The students also learned about *seeing*. For example, they were fascinated with their ability to see and interpret the history of surface features on coins, which was a whole, new world for them. The students discovered that a way to see what and where they wanted involved the hand-held mode of the digital microscope, which made it more like the student's eye. Students really saw for the first time why a bee's stinger hurt when the bee attacked. By really seeing, or noticing real differences and what they meant, the students experienced 'aha' moments of insight as described by the teacher. The progressive steps in digital magnification (10, 60, and 200 power) were like the steps 'close, closer, and even closer.' The students learned the difference between perception and seeing by closely examining objects first and then looking at them magnified. The teacher noted students' haptic perception (requiring touch and handling to fully understand and object).

The *students* themselves worked in pairs, but wanted to interact as a group; all students really wanted their own digital microscope. When students selected their own objects for study or could direct their own inquiry, they were more interested and learned more. The digital microscope changed students' perception of science and scientists in a positive way and students expressed that they felt like young scientists during the lessons. Students doing these lessons showed that they were natural investigators and had natural curiosity. Student discoveries and discourse about the discoveries were the driving forces behind changing direction in the lesson and making them more inquiry-based. Because all students could see each others' computer monitors (and the big screen display), they could all see and share at the same time, which affected the lessons and created a learning community. The students had a strong sense of ownership of the lessons, which emerged from their interest in the lessons and desire to retain digital images and videos and share those with others and at home. All students were fully engaged in the digital microscope lessons.

The *teacher* was excited and confident about the digital microscope and related computer components and software. The teacher wanted to interact with other teachers about the digital microscope and expressed interest in developing a class web-page on digital microscope images. The teacher presented lessons using digital microscopy for which the outcome was not known, and the teacher encouraged student inquiry. The lessons evolved so that students were driving the lessons with their discoveries. The teacher engaged the background knowledge of students to connect them with the technology of digital microscopy and learned along with the students. The teacher encouraged students to look at what interested them in the lessons and in some instances allowed students to bring in objects from outside the classroom for study. The teacher formed a partnership with the students during lessons and encouraged discourse among students and engaged in discourse with them. The teacher used the central big screen as an aid in the lessons and also used a vantage point in the classroom to view all computer monitors in order to follow the lesson and what students were seeing.

Conclusion for the second research question. The digital microscope, computer monitors, and the digital images and prints from those images affected the teacher's way of teaching in lessons using this equipment. These changes included the teacher's main approach, which was to give the students a lesson and allow them to explore using digital microscopy as their natural curiosity engaged them. In this way, the teacher's lessons using digital microscopy became more student-driven and inquiry-based than they would have been without digital microscopy. Also, the way that the teacher directed the lessons changed. The teacher was a partner along with students during the lessons and used the big screen in the classroom and a vantage point in the room where the teacher could see all student computer monitors. The teacher found that the digital microscope was particularly useful in activities with coins and currency, crystals growing in a liquid, and for looking at insects. Coins and currency allowed students to be investigators about the meaning of small marks, printing features, and material compositions. The crystals exercise allowed students to examine geometry and change in natural solids, and the insect exercise put students more in touch with the microscopic aspects of the living world. The remarks of this teacher over the period 2004-2006 suggest that there was a substantial change in the way of instruction of many lessons. This teacher's view of success with these lessons indicated possible long-term change, which was reinforced by success during 2004–2006.

Third Research Question

How does the introduction of the digital microscope into classrooms affect the way that the participant teachers view student learning using digital microscopy? Responses to this question were revealed through several semantic domain categories, as described below.

Characteristic. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *characteristic,* included the following results.

In 2004, the teacher noted that students especially liked to use the hand-held mode of the microscope (E-i-P4-1). Also, the teacher noted that the digital microscope was able to ‘focus quickly,’ which was valuable for students. As the students learned how to manipulate the digital microscope, the teacher was able to observe what the students did as they looked at the objects under magnification (E-i-A4-1).

In 2006, the teacher noted that when the students had control over what they wanted to see, they then developed control over what they may find (E-i-P6-1).

The teacher noted that the digital microscope’s many features ‘really wowed them.’ This reception for the digital microscope was something new for the students – and the teacher – and it showed a shift in attitude for both teacher and students (P6-6).

Comparison. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *comparison*, included the following results.

In 2004, the teacher noticed utterances from students such as ‘oh no, look’ when the students observed an object that at first looked quite plain but as the students looked more closely they found many small, hidden features. The teacher noticed the effect of comparison (unaided view versus microscopic view) upon students and it changed the teacher's view of student learning with digital microscopy (E-ii-P4-1).

The teacher viewed student learning in a new way by considering how the digital microscope might be used outdoors (E-ii-A4-1). In 2006, in using digital microscopy (compared to standard light microscopy), the teacher found out what the students were seeing by looking at the computer monitors and asking them about what they were seeing. The teacher was able to lead the lesson better because the teacher could see what the students were seeing. The digital microscope allowed the students to see change in objects at a different scale and to conduct inquiry at different magnifications (E-ii-P6-3).

The teacher expressed that future lesson planning could include student use of digital images in homework. Compared to the current limitations on homework involving any sort of microscopy, this would be an improvement in the teacher's view. Digital images could be used in the classroom and at home and shared elsewhere with other students and at home with family (E-ii-P6-5).

Computer. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *computer*, included the following results.

In 2004, these responses addressed the third research question:

(1) The teacher noted that the students used digital microscope to initially observe many objects, but as they learned about digital imagery, they made many digital images during the lessons (E-iii-A4-7). The students saved a large photographic record of

the digital images they observed under different magnification and lighting angles (E-iii-P4-1);

(2) The teacher noted how the students used the computer video function of the digital microscope to look at the human eye and record the movement of the human eye. This activity showed the teacher how students could learn using video with the digital microscope (E-iii-P4-4);

(3) The teacher noted that the students liked to use the computer software's special effects. The teacher gained insight into what students wanted to do with the software and thought that student learning was enhanced in this way (E-iii-P4-5);

(4) The teacher found how important the digital microscope's computer capabilities were while observing the students saving digital images and videos in one folder, placing them in their own folder on a file server at the school, opening the files from their folder in another classroom, and later accessing files again from another their homeroom (E-iii-A4-1); and

(5) The teacher noted the experience of the students with other computer programs (used at home or in other classes), which gave confidence to students who were starting out using digital microscope computer technology (E-iii-A4-2). The teacher stated that the students were familiar with 'saving their work' on a computer, which was a routine task for the elementary students. The teacher relied on this routine, and the students' familiarity with it, to get them started with the digital microscope. Also, the teacher found that students knew how to 'launch a program' on a computer, and that helped connect students to the computer software of the digital microscope (E-iii-A4-6).

In 2006, the teacher thought that the computer monitor and the digital microscope were very effective means of focusing student attention during lessons not only because of the remarkable things they saw but also the amount of undivided attention that students' apply to the magnified objects that they were studying (E-iii-P6-1).

Connection. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *connection*, included the following results.

In 2004, the teacher noticed the unexpected connection to art and embraced it in the science-based activities using the digital microscope. The teacher remarked that the students were exploring, manipulating, and imaging objects in different ways, some of which were very artistic. The teacher viewed this as a form of self-expression that was useful in teaching and learning (E-iv-P4-2).

The teacher discovered that students were making interdisciplinary connections on their own using digital microscopy. The teacher's view of student learning in this instance was that students could discover these interconnections for themselves and the teacher allowed them to do so. The teacher felt that students made science-mathematics connections for themselves (E-iv-P4-3).

The teacher viewed student learning in the digital microscope lessons as connecting with two areas of the curriculum, which were taught by two different teachers. The teacher encouraged students to apply what they had learned in *art class* using the digital microscope in a new way to a *science lesson* in the enrichment class. This showed a connection between classrooms and teachers without actual partnership or pre-planned coordination (E-iv-P4-4).

The teacher viewed a digital microscope lesson as more than just a lesson in enlargement; it was a lesson in art as well as science. The teacher felt that the students doing the lesson would progress from counting to studying shapes and other features (E-iv-P4-7).

In 2006, these responses addressed the third research question:

(1) The teacher spoke about the connection with language arts. The teacher noted that the visual aspects of learning also included digital image labeling (use of language), and the teacher encouraged students to modify their saved digital images in this way. Because labeling became part of the lesson, the teacher viewed the lesson as partly a language lesson (E-iv-P6-2);

(2) The teacher noted student learning about digital microscopy in enrichment class was connected to learning in other classes (E-iv-P6-4), and the teacher made the connection that student learning involved making connections and bridges (scaffolding) to prior knowledge (E-iv-P6-5);

(3) The teacher discovered that students learned a great deal when they were allowed to explore and discover on their own and made connections with what they already know. What emerged from these enrichment lessons were authentic science and authentic inquiry. The teacher observed that using digital microscopy promoted authentic inquiry (E-iv-P6-6);

(4) In those instances of students not understanding what they were seeing, the teacher encouraged students to research their questions (make a connection with reference materials in print or on-line in order to supplement the inquiry). Regarding the lessons on U.S. currency, the teacher found that students could use the web-pages of the

U.S. Mint where they could read, for example, about how much time bills of various denominations could exist in normal circulation. The teacher found that students could easily connect with and integrate this knowledge into their lessons (E-iv-P6-8);

(5) The teacher found out that students were surprised by things that they saw and thought about (made a mental connection with). And, the teacher discovered that students had a desire to look at things that were ‘real’ (rather than something ‘made up’) and spent time studying them. Finally, the teacher found out that as students studied things in the lessons, the mathematics connection made sense to them (E-iv-P6-9);

(6) The teacher noted that the students ‘bloomed’ in using the digital microscope, which means that the teacher was receiving positive feedback from the students in the way they were acting and what they were saying. One aspect of this feedback was that students were making connections with what they were seeing. This gave the teacher a positive view of digital microscopy and caused the teacher to think about continued use of digital microscopy in the future lessons (E-iv-P6-11);

(7) The teacher found that using the digital microscope was a way to make a connection to the nature of science with the students (E-iv-P6-13);

(8) The teacher noted that student learning included the connection with ‘seeing change over time,’ which was possible in the lessons using the digital microscope’s video functions. The video functions allowed students to make movies wherein each frame was a ‘snap shot’ taken at a pre-selected time interval such as one second, one minute, etc. (E-iv-P-13);

(9) The teacher felt that digital microscopy and digital imagery presented an opportunity to engage in a discussion about ethics and intellectual property. This came up

during the lessons in which students created and labeled their own digital images. The teacher found this was a unique opportunity for the students to make this connection during these digital microscopy lessons (E-iv-P6-16);

(10) The teacher found that student learning could be aided by having the students work with digital microscope imagery on a class web-page or an external web-site (E-iv-P6-17). The teacher found that the students could learn even more if they made a connection with Internet-based learning regarding digital microscope imagery (E-iv-A6-1). The teacher noted that student learning could be enhanced by using Internet resources, citing the example of other schools, whose students put their class work on-line (E-iv-A6-2);

(11) The teacher noted that students should view the digital microscope as an example of a tool that they might use in a ‘real-life job’ as well as something useful for a classroom lesson. The teacher found that the thought of a job connection helped students understand the importance of learning about digital microscopy (E-iv-P4-3).

Knowing. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *knowing*, included the following results.

In 2004, these responses addressed the third research question:

(1) The teacher expressed a dual view of student learning regarding digital microscopy. The teacher found that students were learning about things they were studying with the digital microscope, but also that they were understanding about being scientists as well (E-v-P4-1);

(2) The teacher noted that students progressively understood more and more about the functions of the digital microscope and that they adapted to using these microscopes for personal inquiry. The teacher observed that the students learned what each part of the digital microscope could do and learned the software functions. The teacher had the view that there were many uses for the digital microscope and that students should explore all those during classroom lessons (E-v-P4-2);

(3) The teacher noted that some students did not initially see that the object and the digital microscope image of the object are the same thing. However, students came to an understanding of the differences with experience using the digital microscope (E-v-P4-4);

(4) After viewing insects using digital microscopy, the teacher noted that students were so impressed with what they saw that 'they will never look at insects the same way.' The teacher intended to use this sort of excitement about insects to encourage students to view and better understand other things as well (E-v-P4-4);

(5) The digital microscope affected the way that the teacher viewed student learning. When the lessons became more student-driven, the teacher felt that the students achieved a different level of understanding of the material. The teacher felt that the digital microscope worked especially well in this regard (E-v-A4-1);

(6) The teacher noted that the students would further their own inquiries and reach a higher level of understanding by asking themselves 'what would some new object look like under the digital microscope.' The teacher felt that student-driven inquiry during which students made their own discoveries in the classroom was the most successful (E-v-A4-2);

(7) The teacher noted that students would come to their own understanding the lesson (and the objects viewed) if allowed to do self-driven inquiry in the classroom using digital microscopy. The teacher felt that the students came to a point where they ‘understood it,’ referring to digital microscopy, the inquiry process, and the objects being studied (E-v-A4-3);

(8) The teacher viewed student learning as being related to their ability to draw from past learning experiences and bring that knowledge into the current lesson involving digital microscopy (E-v-P4-1). The teacher commented that student learning occurred quickly when they were permitted to use the digital microscope to conduct inquiry on topics that interested them (E-v-P4-2). And, the teacher viewed student learning differently after seeing how the students conducted inquiry and communicated among themselves about the results. The teacher viewed the inquiry as successful and productive (E-v-P4-3); and

(9) The teacher felt that the students understood the concepts of scale and magnification better after initially using digital microscopy, so the teacher moved on to lessons involving student inquiry using digital microscopy (E-v-P4-4).

In 2006, the teacher noted that once students realized that they could see progressively more and more fine details, they came to a much deeper understanding of the unseen world. The teacher thought that students could predict that there were even smaller, unseen aspects to the objects they viewed. The teacher felt that digital microscopy was an effective way to show students the unseen world (E-v-P6-1).

The teacher noted that digital microscopy helped all students understand that a microscope did not make objects larger, only the image of the objects is enlarged (E-v-A6-1).

Object. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *object*, included the following results.

In 2004, these responses addressed the third research question:

(1) The teacher viewed digital microscopy as a way to conduct student inquiry on a wide range of materials, objects, and topics. The teacher felt that students would be interested in the microscopic aspects of many different types of objects, both living and non-living (E-vi-P4-5);

(2) The teacher noted that students would benefit greatly from the experience of watching crystal growth from the perspective of digital microscopy. In standard light microscopy, it was not possible for students to see the details of crystal growth as a group activity. The teacher wanted students to view objects that changed over time, such as crystals forming in a liquid (E-vi-A4-1);

(3) The teacher viewed student learning as being driven by their findings about the hidden meaning of an object's attributes, for example, the markings on U.S. coins. The teacher noted that student learning occurred on two levels. The initial level was finding the markings and discussing them among themselves and the second level was researching the markings to interpret what they meant (E-vi-A4-3); and

(4) The teacher observed that students easily understood the details of the finer structure of a man-made object like the doily by using digital microscopy (E-vi-A4-4).

In 2006, these responses addressed the third research question:

(1) Regarding working with growing crystals under the digital microscope, the teacher noted that using the digital microscope made an impression on the students. This contrasted with past lessons when the students watched crystals grow over several days as the crystals simply ‘mounded up’ on a string. Also, the students learned how to manipulate the digital microscope in order to see the crystals better, and the teacher was able to observe what the students did as they looked at the objects under magnification. In addition, the students learned how to set up the digital microscope for digital imagery and time-lapse digital video, and the teacher was able to observe what the students did as they documented the lesson (E-vi-P6-2);

(2) The teacher felt that students learned on their own about the human eye using the digital microscope in the hand-held mode. The teacher noted that the students were fascinated with the human eye and they conducted their own inquiry during enrichment lessons (E-vi-P6-1);

(3) The teacher viewed student learning as working best when students were allowed to conduct inquiry on things that particularly interested them. The students’ observations on skin and hair caused them to be curious about what other things look like under magnification (E-vi-P6-2);

(4) The teacher felt that the students were capable of independent inquiry, which was driven in this instance by their fascination with the fine details embedded in

and printed on U.S. currency (E-vi-P6-3). And, the teacher felt that student learning with digital microscopy was enhanced when the students brought in currency from other countries to conduct inquiry. The students brought in the social studies and history connections to the lessons that were entirely unplanned by the teacher (E-vi-P6-4).

(5) The teacher noted that students could learn effectively by investigating for themselves the composition of objects like paper currency. In this instance, the teacher posed a question about composition and the students learned by seeking the answer using digital microscopy. The teacher felt that student learning in this instance should be driven by their interest in what was emerging from their first look at U.S. currency under the digital microscope. The teacher saw that students were interested and excited and allowed this to continue to drive the lesson (E-vi-P6-5);

(6) The teacher found that the students' way of understanding what they were observing (in this instance, U.S. currency) was to relate the small designs to larger features they had seen before. The teacher noted that the students drove the lesson's inquiry by discussing where they had seen those features before and what they meant. This took the inquiry beyond the study of currency and into other areas such as history and art (E-vi-P6-6);

(7) The teacher found that students were eager to bring in their own interests and previous experiences into the lessons on inquiry involving U.S. currency (E-vi-P6-7). The teacher was informed by the students that the lesson using digital microscopy with coins and currency was their favorite lesson. This encouraged the teacher to want to use this lesson in the future and build upon it (E-vi-P6-1);

(8) The teacher felt that students learned about crystal-growing by observing the activity using digital microscopy and conducting the activity in partnership with the teacher. The teacher felt that students learned more about crystals by observing progressive small-scale changes during growth (E-vi-P6-8). And, the teacher viewed student learning in a positive way after conducting a crystal growing lesson using digital microscopy in which both the teacher and students worked together (E-vi-P6-9); and

(9) The teacher felt that students were particularly fascinated by butterflies and students brought them in for study using digital microscopy. The teacher noted that this student-driven inquiry about butterflies was effective, but also added that students seem fascinated by many things that were observed using the digital microscope (E-vi-P6-2).

Seeing. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *seeing*, included the following results.

In 2004, these responses addressed the third research question:

(1) The teacher noted that during a lesson on insects, some students saw a bee's stinger and what they saw caused them to understand how it was that a bee can hurt someone with its stinger. The teacher commented that students should bring in their experience into studies in ways like this (E-vii-P4-6);

(2) The teacher viewed student learning as being based in part upon prior knowledge and that students brought this prior learning together with what they were seeing. When this happens, there might be a moment of discovery (or 'aha moment') when students really did *see* (E-vii-P4-7);

(3) The teacher viewed the use of simple language to address what the students were seeing as a part of the learning process. The teacher encouraged students to express what they were seeing and interpreting in simple language (E-vii-P4-8);

(4) The teacher expressed that the students saw more things than the teacher expected them to see or notice during their digital microscope lessons (E-vii-A4-3);

(5) The students asked what would the object look like when viewed closer and closer, so the student-driven aspect of the inquiry informed the teacher of the students' desire to look closer at objects (E-vii-A4-2);

(6) The way that the students approached the digital microscope inquiry showed the teacher that they learned about progressive magnification (looking closer and closer) by observing object after object on their own during the inquiry process. The teacher was informed by students that they 'understood it' after using digital microscopy (E-vii-A4-3);

(7) The students enjoyed seeing artistic views of objects they were studying and having those views encouraged students to look more closely at the objects. The teacher was informed of this effect while observing what students did and said as they were exploring and manipulating objects using digital microscopy (E-vii-P4-2);

(8) The students using digital microscopy informed the teacher that they wanted to see closer and closer by using the hand-held mode of viewing larger objects. The teacher noted that the students found ways to manipulate the digital microscope to see what interested them (E-vii-P4-3); and

(9) The teacher noted that student could see better when they were allowed to conduct inquiry on their own using the hand-held mode of the digital microscope (E-vii-A4-2).

In 2006, these responses addressed the third research question:

(1) The teacher noted that personally the teacher had learned a lot about what could be seen looking more closely at objects and the teacher viewed the student learning in much the same way (E-vii-P6-1);

(2) The teacher noted that the discovery by students that they could see progressively finer and finer details of the features on currency drove the student inquiry causing them to look closer and closer at the features they were finding (E-vii-P6-2);

(3) The teacher learned something more about how students see. In this instance, it was through the actual focusing of the digital microscope with their eyes and hands, how they saw an image, then how they focused on the lesson, and finally how this focus became a focus of attention. This attention began in the real experience but was then internalized and transformed and transferred to the behavioral phenomenon of attention. The teacher mentioned that *every student was focused and interested* and that all students were drawn into the lesson using the digital microscope (E-vii-P6-1); and

(4) The teacher noted that students liked to see close-up with the microscope, but they also got closer to the object in terms of being able to better understand its qualities and what those qualities told the student about the nature and origin of the material (E-vii-P6-1). And, the teacher observed that the students were drawn into the lesson by their own questions and the questions caused them to look close and closer (E-vii-P6-6).

Students. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *students*, included the following results.

In 2004, these responses addressed the third research question:

(1) The teacher noted that students first had to learn to focus properly, but when they did, they observed many things, which they immediately discussed with other students (E-viii-A4-4);

(2) The teacher thought that student learning was enriched when students worked in pairs and had a continual discourse about what they were seeing (E-viii-P4-1). The teacher found that students were highly interactive with one another and that they learned from one another during inquiry lessons (E-viii-A4-1). The students informed the teacher when one of the pair of students working with the digital microscope saw something closer and this encouraged the other student to do the same (E-viii-P4-1);

(3) The teacher noted that students were particularly interested in some things, like insects, and that this helped drive student inquiry. Also, the teacher noted the scientific appeal of using the digital microscope was a factor in the success of inquiry lessons (E-viii-P4-2);

(4) The students' fun and enjoyment helped them become engaged in activities using digital microscopy in inquiry (E-viii-P4-3). Also, the teacher thought that the students' natural inquisitiveness helped engaged them in inquiry lessons using digital microscopy (E-viii-P4-4). The teacher felt that students learned more if they were excited and part of that excitement included sharing discoveries with others (E-viii-A4-4);

(5) The teacher thought that students began to think of science differently after using digital microscopy and this positively affected the teacher's view of enrichment lessons using the new technology (E-viii-P4-4);

(6) The teacher found that students responded the most to digital microscope inquiry lessons when they brought in the things that *they* wanted to look at under magnification (E-viii-A4-2). And, the teacher thought that student learning was enhanced when the students were allowed to pursue *their interests* in the inquiry lesson (E-viii-A4-3) including objects from outside the classroom that they were interested in (E-viii-A4-2);

(7) The teacher noted that the actions of students using the digital microscope and how quickly they learned informed the teacher that students want to look closer and closer at objects that interest them and hold their attention (E-viii-P4-2). The teacher was informed that the students wanted to see closer and closer by the ongoing discourse about the objects being observed during the lesson (E-viii-P4-3). And, the teacher was informed that the students were looking closely at coins by the many discoveries they made about coin features and markings on the surfaces. This caused the students to want to look more closely, not only at the features, but at the origin of the features (E-viii-A4-3);

(8) As the students learned the parts of the digital microscope and their functions, their observations informed the teacher that they knew more about the concept of scale and 'closeness' of view (E-viii-P4-2). The teacher was informed about students seeing closer and closer by the way that students related the objects they were working with to the images on the computer monitor, which was hooked up to the digital microscope (E-viii-P4-4);

(9) The students expressed a more creative side of seeing close and closer in the way that the students enhanced their digital images and videos using the digital microscope software (E-viii-P4-5). And, the teacher found the students enjoyed the digital imaging capability of the digital microscope, which allowed the students to see in a different way, much closer, than a traditional camera. In particular, the digital video allowed the students to see the object up close and then closer (E-viii-A4-4);

(10) The students looked closer and more closely and made various utterances about what they were seeing (‘wow, look at this’), which alerted other students to their discovery (E-viii-P4-1). Also, the teacher noted that students saw so many things under the digital microscope (E-viii-A4-3);

(11) The students used the digital microscope’s software to store images and as a result they wanted to share them by sending them home electronically. The teacher discovered that the students had a keen interest in saving and sharing what they discovered. This reflected the students’ sense of ownership of the lessons’ findings (E-viii-P4-1);

(12) The teacher thought it was remarkable that knowledge the students gained in art class, which used the same kind of digital microscope set up, also helped them in the enrichment class (E-viii-P4-2); and

(13) The students liked to manipulate objects as well as simply view them using digital microscopy. The teacher observed that students naturally manipulate objects while studying them in this way (E-viii-A4-1). And, the teacher noted that the students needed to handle the objects being studied as well as viewing them under the digital microscope (E-viii-A4-6).

In 2006, these responses addressed the third research question:

(1) Student learning in these enrichment lessons was being driven by student curiosity and level of interest and curiosity in studying things like currency using digital microscopy (E-viii-P6-2). The teacher viewed student learning as more individual, because some students had such different perceptions of what they were seeing during the inquiry involving digital microscopy (E-viii-A6-1);

(2) The teacher viewed student learning as being affected by the lack of experience and perception under high magnification. The teacher felt it important to note that students did not have a good way to predict or understand what they were seeing at high magnification. The world at high magnification was much farther from their experience than low magnification (E-viii-A6-1);

(3) The students were learning more about focusing and adjusting to accidental ‘bumps’ by their own trial and error and by discourse among one another (E-viii-A6-2). And, the teacher viewed inquiry-based learning as a trial and error process where some students would not initially recognize what they were observing using digital microscopy (E-viii-P6-1);

(4) Student discourse became a driving force in the enrichment lessons using digital microscopy. The teacher found that observing student discourse from a vantage point in the classroom was effective, for example, the lesson on U.S. currency (E-viii-P6-5);

(5) Student learning was enhanced when all students could see each others’ computer monitors, speak to each other, and participate in the digital microscope lesson.

This was also facilitated by a central big-screen display in the classroom (E-viii-P6-6). With this arrangement, all students were participants in the lesson (E-viii-P6-7; P6-8);

(6) The students each wanted their own digital microscope, which caused the teacher to consider if this might be the best arrangement considering the interest level in digital microscopy (E-viii-P6-9). However, in view of the limited number of digital microscopes teacher felt that having two students per digital microscope was the way that the students preferred doing their inquiry lessons (E-viii-A6-11; A6-12). The teacher thought that more students per digital microscope would result in uneven distribution of time on the digital microscope (E-viii-A6-12);

(7) In one instance, the students were interested in what they could see with the digital microscope and how it related to the reasons for washing their hands. The teacher used this curiosity about hand washing to encourage inquiry using digital microscopy (E-viii-P6-11);

(8) The students learned readily about magnification in using digital microscopy to observe common objects up close (E-viii-P6-12). And, the teacher felt that student learning was enhanced by encouraging students to use digital microscopy to examine the details of common objects that students were interested in seeing (E-viii-P6-13; P6-14);

(9) The students had a sense of ownership of the digital microscope itself and their findings with it and this encouraged the students to perform their inquiry lessons (E-viii-P6-16). The teacher felt that students were amazed at what they were finding and seeing, that students felt a sense of ownership of their work, and that students learned much from other students during discourse (E-viii-A6-5). And, the teacher viewed

student learning as being enhanced by the students' desire to preserve their work and have a sense of ownership of what they found and the images that they made (E-viii-A6-7). Also, the teacher viewed student ownership and their interest in inspiring imagery taken with the digital microscope as motivators in learning (E-viii-A6-9);

(10) The students had an unexpected, sustained interest in digital microscopy and its various interdisciplinary connections. The teacher viewed these as positive aspects of lessons using the digital microscope (E-viii-P6-17; P6-18);

(11) The students' learning increased when students took the time to look thoroughly at what they were seeing under the digital microscope (E-viii-P6-19). The teacher found that student learning was enhanced by encouraging students to think about prior experiences and previous learning experiences (E-viii-P6-20). And, the teacher observed that the students' learning was enhanced when they were encouraged to handle the coins being studied rather than just look up the coins on the Internet (E-viii-P6-21);

(12) The students readily adapted to looking at the differences in what light that passes through an object could show you versus light that reflected off the object (E-viii-P6-22; P6-23);

(13) The students gained necessary 'instant gratification,' in the teacher's view, by being able to save digital images as they went along in the lessons (E-viii-P6-24);

(14) Student learning was enhanced by the students' ability to capture and print out digital images during digital microscopy lessons and use these artistic and scientific graphics in their reports and posters (E-viii-P6-26). Also, the students were able to see previously studied objects in more detail by studying their digital imagery and this resulted in students reconsidering how to classify the imaged objects (E-viii-P6-25);

(15) The students were sensitive about doing something that others had done before. In the inquiry lessons, students wanted to feel as if they were the first to do the inquiry on that particular topic (E-viii-P6-27);

(16) The students seemed to work together better and with fewer problems when using digital microscopy. The teacher noted that reduction in behavior problems among students working together helped the inquiry lessons go more smoothly (E-viii-A6-3);

(17) The students tended to make connections to past experiences during inquiry lessons when they were allowed the opportunity to do so (E-viii-A6-6). The teacher noted that students came to the classroom with some prior knowledge of digital technology (from digital cameras and video cameras) and that this made learning about digital microscopy easier (E-viii-A6-10);

(18) Students' excitement about what they were learning helped drive their inquiries using digital microscopy (E-viii-A6-8). The teacher felt that students viewed themselves in a new, positive way as young scientists using the digital microscopes (E-viii-A6-13);

(19) The students became more seasoned investigators as they progressed in their lessons (E-viii-P6-1);

(20) The student's use of the digital microscope and their many excited comments and gestures informed the teacher of their interest in looking ever more closely at magnified objects (E-viii-P6-13; P6-14). The students were already looking closely at the plants that they were growing, and the digital microscope was included in this activity in order for the students to see closer and closer (E-viii-P6-10);

(21) Different magnification levels of the digital microscope allowed students to experience the phenomenon of ‘close, closer, and even closer’ for themselves. The students learned about the unseen world and described their discoveries and findings to their teacher (E-viii-P6-1). The teacher was informed of how the students see in this regard by what the students were doing and saying. The students better understood the concept of magnification as a result of looking closer and closer at objects (E-viii-A6-1);

(22) Students using the digital microscope informed the teacher that they were seeing closer and understanding the composition of U.S. currency by looking at progressively higher magnification. As the students discovered more and more about U.S. currency, this encouraged the students to look more and more closely at the currency. The teacher was informed of what they were seeing and this helped drive the lesson (E-viii-P6-5). The digital microscope itself informed the teacher because the teacher could see the student’s results on the computer monitor and in digital images that the computer stored (E-viii-P6-6); and

(23) Students worked in a safe environment that the teacher provided for them, which was evident in their ability to freely share what they were going to do as well as being confident to go in the direction that they wanted to and were interested in. In this way, the teacher was able to discover what interests the students and what they were capable of doing, to gain a glimpse into what prior knowledge they were bringing to the task, and to have then a great teaching moment of being able to share with the students what they wanted to do with the picture (E-viii-A6-2).

Teacher. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *teacher*, included the following results.

In 2004, these responses addressed the third research question:

(1) The teacher viewed student learning in a new way after using digital microscopy in an enrichment lesson. The teacher observed that the children were fascinated with the new technology and their enthusiasm and curiosity helped drive the lesson. The teacher allowed students freedom to learn for themselves (E-ix-P4-1);

(2) The teacher observed much student discourse during the enrichment lesson and viewed the discourse during inquiry as being very important in the lessons involving digital microscopy (E-ix-P4-2). The teacher viewed the combination of student observation and discourse as the thing that made the regular lessons into inquiry lessons. The teacher participated in the process, but the process was mainly student-driven (E-ix-P4-5).

(3) The teacher felt that students would find new ways to use the digital microscope in the enrichment lessons without specific instructions from the teacher. For example, the students used the hand-held mode for objects of size without being prompted to do so. The teacher viewed student learning as being driven by natural student curiosity (E-ix-P4-3);

(4) The teacher's observed the unusual interest level shown by students who brought in various objects from outside the classroom that they wished to study with the digital microscope. The teacher allowed them to study these objects and made them part of the lessons (E-ix-P4-4); and

(5) The teacher felt that the students understood from the lesson how a simple question could be answered by using digital microscopy. The teacher noted that it useful to have the students form their own question and answer it. Also, the teacher felt that it was important for students to engage in inquiry that produced results that some were not expecting. This ‘surprise factor’ was viewed as important in the enrichment classes’ inquiry activities (E-ix-A4-5).

In 2006, these responses addressed the third research question:

(1) The teacher noted that students had learned a lot about the digital microscope technology and the teacher wanted to learn more about it as well (E-ix-P6-1). The teacher felt that if the teacher could find new ways to use the new technology, then the students should be able to also (E-ix-P6-9);

(2) The teacher felt that students would be as excited as the teacher was in making discoveries with the digital microscope (E-ix-P6-8). The teacher felt that the students were confident in using the digital microscope because the teacher was confident in doing so (E-ix-P6-7; A6-1);

(3) The teacher noted that students enjoyed their experiences using digital microscopy and that this added to the lessons’ effectiveness and the students’ willingness to produce high-quality results (E-ix-P6-2). And, the teacher felt that students would naturally take the opportunity to be creative and artistic in their work and the teacher encouraged them to do so (E-ix-A6-9);

(4) The teacher mentioned that students were more motivated to learn about digital microscopy if they were allowed to thoroughly examine the things that they chose to study (E-ix-P6-3). And, the teacher felt that students did very well when they were

allowed to contribute to the lesson by bringing in things they liked to observe and had considered beforehand (E-ix-P6-4);

(5) The teacher noted that the students needed time to think about where digital microscopy came from and where future technology was headed. The teacher thought that students also gained a perspective on this from working with the digital microscopes (E-ix-P6-5);

(6) The teacher noted that the digital microscope technology allowed students to learn better on their own how to focus and manipulate objects under the digital microscope (E-ix-P6-6);

(7) The teacher noted that students could create many digital images and videos for their lessons, and these files could be labeled and put into digital folders properly in order for students to do their lessons effectively and later share the results with others (E-ix-A6-2);

(8) The teacher found that students were interested in learning about other areas of the curriculum, including art, using digital microscopy (E-ix-A6-3). The teacher felt that students understood better the interconnections between different disciplines of study in the context of using the digital microscope during enrichment lessons (E-ix-A6-7);

(9) The teacher found that partnering with the students in the learning process would benefit both the students and the teacher (E-ix-A6-4). The teacher thought that the students would learn more effectively if the teacher formed a learning partnership with them during digital microscope lessons (E-ix-A6-5);

(10) The teacher was able to better monitor student learning by seeing all computer monitors at the same time and this affirmed to the teacher the effectiveness of the lesson and how well the students were staying on the topic of the inquiry (E-ix-A6-8);

(11) The teacher noted that the students had much to say about the progress of the lessons involving digital microscopy, so the teacher listened and watched the students. This gave information to the teacher on how to guide the lessons and this was a great help to the teacher (E-ix-A6-10). And, the teacher felt that students learned well in student-driven inquiry and was guided by the teacher's own feelings about such inquiry (E-ix-A6-6);

(12) The teacher noted the ability of students to get closer to the lesson using digital microscopy and actually be observers participating in watching the crystal growth process in real time. The students learned how to use the digital video function for this lesson (E-ix-P6-2);

(13) The teacher found the importance of not having to worry about the possibility of the students bumping into the microscope and changing what was being viewed (E-ix-P6-3);

(14) The teacher spoke about the lesson on paper currency under the digital microscope and how the students observed more and more closely and in this way formed more and more questions about what they were seeing, which surprised the students (E-ix-P6-3);

(15) The teacher noted that compared to the hand lens and the standard light microscope, which were used in inquiry lessons in the past, the students preferred using the digital microscope (E-ix-P6-3; P6-4);

(16) The teacher felt that students could integrate digital microscopy into an on-going lesson (where digital microscopy was not used at the outset of the lesson) and that this would work out well and would enhance the on-going lesson (E-ix-P6-10);

(17) The teacher viewed the use of digital microscopy as a way to include *all* students in the inquiry activity (E-ix-A6-1). And, the teacher found that the whole classroom group worked together and encouraged each other to try new ways to see with digital microscopy (E-ix-A6-2);

(18) The teacher felt that the digital microscope set-up allowed the teacher to be part of the inquiry process because all the students' monitors could be viewed by the teacher and the teacher could ask questions as the students were making their discoveries (E-ix-A6-4); and

(19) The teacher learned by what the students looked at and recorded as a video. The teacher was further informed when the students played the video and noticed things that they did not see originally. The teacher also noted that the students had learned how to use all the functions of the digital microscope (E-ix-P6-1).

Summary of the third research question. The participant teacher's way of viewing student learning using digital microscopy was affected by the digital microscope's *characteristics*, which gave students control over what they wanted to see during the lessons and 'really wowed them' according to the teacher.

Students made *comparisons* using digital microscopy, especially among things that they were discovering. The teacher noted that students would beckon one another over for a view of some new discovery, saying 'oh no, come look.' Comparing the apparent plainness of an object with its unseen, microscopic aspects were an endless source of new information for students. Compared to the light microscope, the digital microscope aided student learning greatly (mainly for its stimulation of exploration and community learning and its capability to make and store digital files).

The *computer* aspects of the digital microscope included the capability to create and store vast numbers of digital images and videos. The teacher remarked on the student's fascination with making these images and videos, and in some instances modifying them with the software's special effects. The teacher noted that the digital microscope's features commanded the student's undivided attention.

The teacher remarked that students made many *connections* on their own while using digital microscopy, including seeing artistic views of science lessons, interdisciplinary connections, language arts connections, feeling like a scientist, appreciating intellectual property rights, and what it is like to use equipment in a 'real life job.' Also, the students wanted to contribute to a class web-page on digital microscopy.

The teacher noted that students appreciated 'change over time' more after making time-lapse digital video records of crystals growing. The teacher noted that students understood concepts better because they could now answer the question 'I wonder what this would look like under the digital microscope?' by placing items under the digital microscope. To really understand what they were seeing, the teacher noted that students should first relate what they saw to something they might have seen before (i.e., draw on past knowledge). Using the digital microscope, the students learned about the difference between just looking at an object and gaining a deeper understanding of the nature of the object.

The *objects* that students examined could have been impersonal, but the teacher asked students to select their own objects for study whether they came from inside the room or were brought in by students. This personal connection made the study of objects more meaningful to the students because they had a connection to them. The students were interested in whether or not something was man-made or natural. They were fascinated especially by coins, currency, crystals, and insects. Students noticed differences in things, by magnifying them progressively.

As the students drew close and closer to the bee’s stinger, they noticed how it can sting (i.e., pierce the skin with a sharp point). Prior knowledge was important in students’ *seeing* and understanding the qualities that they observed during the lessons.

In the teacher’s view, the *students* learned by using the digital microscope and from other students in the classroom learning community who were doing the same thing at the same time. They alerted each other to discoveries and all could see what others were finding on the computer monitors. Fun and excitement were important things to the students, in the teacher’s view, and so too was being able to look at what they wanted to study during lessons using digital microscopy. Students’ ongoing discourse during lessons informed the teacher of what they were thinking and doing. The students’ creative side came out in the lessons and their curiosity was a driving force in the lessons’ successful outcomes. Lack of experience did not deter students, but they did rely on some previous knowledge from art class and from experiences at home, which the teacher found remarkable. The students saw science differently after doing some lessons using digital microscopy. Each student wanted his or her own digital microscope and there was a sense of ownership expressed about the digital microscopes and the digital images and videos made with them. There were no behavioral problems during digital microscope lessons.

The *teacher* viewed student learning in a new way after using digital microscopy, saying that students were naturally curious and could have started the lessons and made discoveries almost as if the teacher were not there. The teacher felt successful about engaging student inquiry during the lessons and was excited along with the students in their discoveries. The teacher noted that students seemed to take every opportunity to be creative in their lessons using digital microscopy. The teacher noted that students needed time to think about what they were doing and seeing, and that they had a great capacity for learning on their own. The teacher found that students naturally made connections to other areas with what they were seeing and this came out in the digital microscope lessons. The teacher found that all students were engaged in the lessons, which was another benefit of the new tools.

Conclusion for the third research question. Using the digital microscope, including the computer monitors and digital imagery and sketches from those images, affected the teacher's view of student learning during lessons involving this equipment. These changes included the way that the digital microscope encouraged student creativity and inquiry skills to emerge during the lessons. The teacher felt that students naturally found interconnections among subjects while doing digital microscope-based lessons and were naturally curious. The observations of this teacher over the period 2004-2006 about what the teacher viewed as the overall success of using digital microscopy in enrichment lessons suggested that there was a change in the way that the teacher viewed student learning during lessons that involved digital microscopy.

Findings for Teacher A

First Research Question

How does the introduction of the digital microscope into classrooms affect the way that the participant teachers view science and technology? Responses to this question were revealed through several semantic domain categories, as described below.

Characteristic. The view of this participant teacher about science and technology, as revealed through the semantic domain category *characteristic,* included the following results.

In 2004, the teacher viewed the digital microscope as child-friendly technology that was an important learning tool. The teacher was receptive to the introduction of digital microscopy technology into an art class, where the previously used tools were an artist's view finder and a magnifying glass (A-i-P4-2; P4-4). The teacher expressed the view that the new technology of the digital microscope made the art lesson much easier to supervise and permitted the students to explore more than previous methods (A-i-P4-5; P4-6). And, the teacher viewed digital microscopy as being practical and suitable for the teacher's art lessons. This led to a positive feeling about this type of technology in future lessons (A-i-A4-2).

In 2006, the teacher found that the students were able to use the portable aspects (i.e., the hand held mode) of the new digital microscope technology to be able to see what they wanted to observe. This was viewed as a great improvement in technology by the teacher (A-i-P6-2). The teacher viewed the new technology as easy to set up and practical to use, which encouraged the teacher to use this technology (A-i-A6-1). And, the teacher found that students were attracted to the technological aspects of the digital microscope and this helped them in their lessons and encouraged the teacher to use the technology more often in art lessons (A-i-A6-2).

Comparison. The view of this participant teacher about science and technology, as revealed through the semantic domain category *comparison*, included the following results.

In 2004, the teacher noted that the new technology was flexible and therefore was much better for art lessons than the standard light microscopes (A-ii-P4-1). And, the teacher viewed the digital microscope technology as being much better than previous methods of doing some kinds of art lessons. For example, the digital microscope's view was better than the view in the artist's view finder because it provided an enlarged view while blocking out the surrounding area and it was better than the standard light microscope because all students and the teacher could see what each magnified view looked like all at the same time (A-ii-A4-1).

In 2006, the teacher found that the hand-held mode of the digital microscope technology was most useful in the art lessons the teacher had planned because it allowed students to look at objects that could not fit under the stage of any microscope or that could not be moved to the classroom. This characteristic of the digital microscope gave the teacher a positive feeling about wide usefulness of this new technology (A-ii-P6-1).

Connection. The view of this participant teacher about science and technology, as revealed through the semantic domain category *connection*, included the following results.

In 2004, the teacher observed that a new technology, the digital microscope, opened up 'new options' as any new technology likely would do. The teacher expressed the view that new technology likely improved learning in the art classroom (A-iv-P4-1).

In 2006, the teacher observed that the new technology, allowed students to better connect with other parts of the curriculum and to the biology of flowers in particular. The teacher felt this new technology was an improvement in this regard (A-iv-P6-2).

Knowing, object, and seeing. The view of this participant teacher about science and technology, as revealed through the semantic domain categories *knowing, object, and seeing*, included the following results.

In 2004, the teacher noted that the new technology stimulated students to think and write in new and better ways (A-v-P4-1).

The teacher felt that the new technology gave a different view than the human eye, a view that the teacher described as 'more confined.' The teacher felt that this view was very useful for students doing art lessons on natural art objects (A-vii-P4-2).

In 2006, the teacher felt that the new technology made it much easier for students to engage in exploration of art objects and their art environment (A-vi-P6-1).

The teacher noted that the new technology functioned much like the artist's eye would in capturing the 'deeper view' of art objects (A-vii-P6-1).

The teacher noted that some higher power images were abstract to some students because they were not accustomed to seeing small things at such levels of enlargement (A-vii-P6-5).

Students. The view of this participant teacher about science and technology, as revealed through the semantic domain category *students*, included the following results.

In 2004, the teacher noted that the new technology of the digital microscope amazed the students and captured their attention, perhaps more so than the teacher had expected (A-viii-P4-1). The teacher found that the new technology of the digital microscope, especially its hand-held mode, worked very well in art lessons because of the way that the students wanted to work. The hand-held mode helped students see what they wanted to see, which was an important consideration during the art lessons (A-viii-A4-2). And, the teacher felt that the technology appealed to both genders in the classroom equally (A-viii-A4-6).

About the new technology, the teacher noted that watching what was being discovered by other students on the students' computer monitors and on the big screen in the front of the room helped students explore and learn during the art lessons (A-viii-A4-4).

In 2006, the teacher thought that the new technology brought out feelings and understandings in the students that did not come out when older technology (e.g., a standard light microscope) was used in the past (A-viii-P6-2). The teacher noted that the new technology of digital microscopy helped students in sharing their findings, which led to their greater insight into the art lessons (A-viii-P6-4).

Regarding new technology, the teacher used the central big screen in the classroom to display digital microscope images so all students could see and share at the same time. This supplemented the computer monitors that all students could see during the lesson. This new technological approach allowed students to see what others were seeing all at the same time, which stimulated discourse (A-viii-P6-3). And, the teacher found that the new technology engrossed the students (A-viii-P6-5).

Teacher. The view of this participant teacher about science and technology, as revealed through the semantic domain category *teacher*, included the following results.

In 2004, the teacher found that the new technology gave the teacher and the students an artistic, yet magnified view of natural things (A-ix-P4-2). The teacher noted that the technology of the digital microscope permitted the teacher and the art students to accurately simulate the artistic perspective of the artist Georgia O'Keeffe, who is celebrated for her large paintings of small flowers and shells (A-ix-P4-1). The teacher mentioned that the printing technology combined with the digital microscope technology made the art lessons on the style of Georgia O'Keeffe much more effective than it ever was with more simple devices such as an artists' view finder (A-ix-P4-1).

The teacher noted that the new technology completely engaged the students in discovery so much so that they did not want to stop working on their art lessons (A-ix-P4-2). And, the teacher commented that the new technology allowed the teacher to attain results in student performance in specific art lessons that had never been attained before using any other method (A-ix-P4-3). Specifically, the teacher noted that students were more focused on the objects at hand using digital microscope than the simple artist's view finders used in the past (A-ix-A4-1). And, the teacher's view of technology (regarding digital microscopy and related computer devices) was that it worked so well in art lessons and that the student discovery process was so much improved that the teacher wanted to share the technology with other teachers and get their ideas (A-ix-P4-3; P4-5).

The teacher viewed the technology of the central big-screen display, in addition to the various student computer monitors, as a great improvement in the teacher' ability to see and understand what the students were learning in the art lessons using digital microscopy (A-ix-P4-4).

In 2006, the teacher noted the digital microscope technology was so effective in stimulating student interest and fascination in learning that the students requested extra time to do their assignments (A-ix-P6-1).

The teacher's view of the technology of digital microscopy was very positive and this motivated the teacher to express a desire to share the technology with other teachers, continue the scientist-teacher partnership, and create a class web-page for sharing digital imagery among students and teachers (A-ix-P6-2; P6-4). After using the new technology for art lessons, the teacher wanted to know more about how other teachers set up their classrooms for such lessons and how they stored digital information (A-ix-P6-5).

The teacher felt that the digital microscope technology allowed the teacher to see in a completely new way and to convey this to the art students (A-ix-P6-3), and for this reason the teacher felt that the new technology was especially effective in the teacher's art lessons (A-ix-P6-4).

Summary of the first research question. The teacher's view of the science and technology of the digital microscope and the related computers, computer monitors, and big-screen displays was that their characteristics permitted a vast improvement in the teacher's ability to instruct students in art lessons and in student interest in art lessons where digital microscopy was involved. The stored and printed images permitted new ways of conducting art lessons, including drawing and painting. This technology, compared to methods used in the past, was far superior. The technology enabled connections to other curriculum areas and enabled students to engage in lessons of art inquiry that were not possible before. Student interest was so great that students asked for more time and did not want to stop working on their projects. The teacher could see what was going on during the lessons and better understand what students were learning. The teacher, inspired by the new technology, wanted to share with other teachers and wanted to make a class web-page on digital imagery.

Conclusion for the first research question. The new technological tool (the digital microscope), related computer and big-screen displays, and storing and printing digital images affected the teacher's view of teaching art with this equipment in such a way that there was a potentially long-term change in instruction of some art lessons.

Second Research Question

How does the introduction of the digital microscope into classrooms affect the way that the participant teachers teach their classes that use digital microscopy? Responses to this question were revealed through several semantic domain categories, as described below.

Characteristic. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *characteristic,* included the following results.

In 2004, the teacher noted that exploration with the digital microscope was important to the art lessons and that the characteristics of the digital microscope enhanced this exploration. Specifically, the teacher:

(1) recognized the students' need for individual inquiry and allowed students to pursue this using the digital microscope (A-i-P4-1);

(2) allowed the students to explore art objects in the classroom that interested them and then encouraged the students to give their own direction to the art lesson using digital microscopy (A-i-P4-2; P4-4);

(3) encouraged student work with each other and, further, the teacher worked with the students and collaborated with them (A-i-P4-2); and

(4) asked students to individually direct their own inquiry using the digital microscope and art objects, for example, in selecting objects to work with and in placing light where the students wanted it on the art objects (A-i-P4-4; P4-5).

The teacher found that the digital microscope helped focus student attention on the areas where the teacher wanted students to look and used this focusing ability in the lessons. This was an improvement in the teacher's view over using the simple artist's view finders and magnifying glasses as in the past (A-i-A4-1). And, the teacher employed the digital microscope's ability to help students focus on what they wanted to see, the teacher asked students to make digital images of the art objects in the lesson. The use of this digital imagery was different from lessons in the past, when the teacher gave students an artist's view finder or magnifying glasses, and then asked students to make sketches of what they saw during similar art lessons (A-i-A4-2).

The teacher felt that the digital imaging aspect of the digital microscope contributed to the student sense of ownership of the digital images and work products of the art lessons (A-i-A4-1; A4-2).

Also, the teacher mentioned that the digital microscopes were not burdensome or too time-consuming to use, in fact, the teacher felt that it was worthwhile to use them as much as possible (A-i-P4-3).

In 2006, the teacher was open to the students:

(1) using the digital microscope's computer software graphics programs to create artistically enhanced versions of their digital images, including images with 'flipped colors' and images that the teacher described as 'an Andy Warhol kind of thing' (A-i-P6-1);

(2) using the hand-held mode of the digital microscope (i.e., taking the digital microscope off its base) in order to observe what they wanted to see, which included a wider variety of art objects and materials (A-i-P6-2);

(3) wanting the lessons to be more open-ended as a result of the students' expressed interest in using the digital microscope and related digital imagery for inquiry (A-i-P6-2); and

(4) learning much by simply exploring and sharing what they were finding as they observed art objects using digital microscopy (and the teacher participated with them in this exploration of art objects) (A-i-P6-3).

Also, the teacher mentioned that the digital microscopes were easy to set up and put away (A-i-A6-1). And, the teacher used the visual appeal of the digital microscope to draw them into the art lessons (A-i-A6-2).

Comparison. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *comparison*, included the following results.

In 2004, the teacher noted that compared to other equipment used in art class the digital microscope was a good way to help students focus on one limited area of the art object and not be concerned with the whole art object. In viewing a fresh flower, for example, the students viewed only parts of the flower leaving the balance unseen, which was the objective of the lesson (A-ii-A4-1). The teacher used the digital microscope to help achieve the artistic, close-up view of natural objects (in this instance, fresh flowers) in the magnified style of the artist Georgia O'Keeffe. The teacher specifically wanted the focused, close-up view that the digital microscope achieved to be used in the lessons because no other device that the teacher knew could give this effect (A-ii-A4-2).

In 2006, the teacher noted that the hand-held mode of the digital microscope, versus other enlargement techniques, afforded students an opportunity to look at objects (in this instance, fresh flowers) that they could not see otherwise. By comparison, with a standard light microscope the flower might be crushed on the microscope's stage. The digital microscope also allowed students to achieve a lighting effect upon the art object in a way that was not possible with other means (standard light microscope or magnifying glass) (A-ii-P6-1).

Connection. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *connection*, included the following results.

In 2004, the teacher viewed the digital microscope as a new tool that potentially could have a great benefit connecting to art lessons. The teacher viewed the digital microscope as a practical new tool that students apparently liked to use (A-iv-P4-1). In using the digital microscope, the teacher discovered:

(1) that there was a natural connection between artistic images and scientific images that the students produced and as the teacher brought this out in the art lessons, the students commented on this as well (A-iv-P4-2);

(2) that students obtained a more complete, yet appropriately restricted view of art objects, which the teacher had encouraged them to attain in their lessons so that the students could connect with certain art styles (A-iv-A4-1);

(3) that students seem to naturally manipulate art objects while using the digital microscope in order to obtain the proper lighting that achieved desired effects, which connected to classroom art lessons (A-iv-A4-2); and

(4) the digital microscope stimulated student interaction and discourse, and also had the effect of stimulating student writing about art work during art lessons (A-iv-P4-1).

The teacher also discovered that the digital microscope functioned well as a means for students to achieve a view of art objects that connected to and mimicked the view of the artist Georgia O'Keeffe who envisioned the detail of oversized flowers and other natural objects in her paintings (A-iv-A4-3). The teacher wanted the students to view the art objects similar to the way that the artist Georgia O'Keeffe as possible and specifically used the digital microscope and its unique way of seeing ordinary objects in new ways to achieve this goal (A-iv-A4-3).

In 2006, the teacher noted that using the digital microscope stimulated students' writing and this helped connect the lessons to other parts of the curriculum. Changing the lessons slightly, the teacher encouraged students to think and write about what they saw (A-iv-P6-1). The teacher discovered that the digital microscope helped connect different parts of the elementary curriculum and that this helped meet state standards. The teacher viewed this as a good reason to include more digital microscopy in art lessons in the future (A-iv-P6-2).

The teacher also discovered that:

(1) it was important for students to look at the nature of art materials under the digital microscope in order to connect with the textural differences in those materials (A-iv-A6-1);

(2) both the art and science aspects of the art lessons on natural materials could be combined in the art lessons and this combination was viewed in a positive way by both the teacher and the students (A-iv-A6-2); and

(3) the digital microscope continued to be a very effective way to make the visual connection to the style of famed artist Georgia O'Keeffe, who painted natural things like flowers in a limited, yet highly magnified way (A-iv-A6-3).

Object. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *object*, included the following results.

In 2004, the teacher allowed students to explore by looking at their own eyes, hair, face, etc. before moving on to looking at art objects (A-vi-P4-1).

Also, the teacher encouraged students to examine the art materials (e.g., yarn, clay, etc.) that they used in art lessons using the digital microscope. The intent of this examination was so the students better understood the actual texture and make up of these art materials (A-vi-P4-1).

In 2006, the teacher allowed students to bring in outside objects, which had the effect of stimulating student artistic discovery and inquiry (A-vi-P6-2).

The teacher found even though there were time constraints on what the teacher could do in terms of digital microscope lessons, the extra allotted time was well spent and the students enjoyed looking at a variety of different objects as well as the flowers and shells used in the Georgia O'Keeffe-style art lessons (A-vi-A6-1).

Seeing. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *seeing*, included the following results.

In 2004, the teacher allowed students to manipulate various objects and spend time looking at them and studying their properties, which the teacher saw as part of the art lessons using digital microscopy. In so doing, the teacher engaged the students' natural fascination with seeing the microscopic world in the art lessons (A-vii-P4-1).

The teacher also allowed students to explore art objects using the digital images they made of objects in the computer laboratory and then spend time in the classroom looking at those images in order to do sketching, drawing, and painting of the objects. In this way, the students had two experiences seeing the art objects – once under the digital microscope and once using the digital images they made (A-vii-P4-1).

The teacher used the digital microscope's way of seeing to achieve a different view of natural art objects, a view that was more comprehensive yet confined. The teacher felt this way of seeing was very useful in achieving the results that the teacher wanted from the art lessons (A-vii-P4-2).

In 2006, the teacher found that students were fascinated with the ways they could see using digital microscopes during exploration in art lessons and that the students tended to be particularly fascinated with seeing the unusual. The teacher asked the students to look closely at the shape, color, and texture of the specific art objects that they were seeing (A-vii-P6-1).

The teacher wanted students to have an artist's view of the art objects and used the digital microscope to achieve that view. The teacher allowed students to explore art with the digital microscope by looking in particular at flowers and shells (A-vii-A6-1), but the teacher observed that students also worked well when they were permitted to decide what art objects they could work with and when the teacher was a participant in the art lessons (A-vii-A6-2).

Students. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *students*, included the following results.

In 2004, these responses addressed the second research question:

(1) The teacher found that students preferred to work as a group and permitted them to do so. The teacher found that the students were amazed at what they were seeing and interacted with each other by talking and gesturing (pointing) (A-viii-P4-1);

(2) The teacher noted that students shared in their discoveries and in the process learned from each other (A-viii-A4-1). And, the teacher noted spontaneous student discourse and those students naturally watched what others were doing as part of the art lessons using digital microscopy (A-viii-A4-4);

(3) The teacher asked students to use various elements of art, but allowed them to do so in their own way using the digital microscope (A-viii-A4-2);

(4) The teacher engaged all students in a high level of interest in art activities using digital microscopy. The teacher found that the digital microscope engaged the students and captured their attention and imagination (A-viii-A4-6);

(5) The teacher felt a sense of ownership of the art lesson on the part of the students relative to the digital imagery and other results of the art lessons (A-viii-A4-5);

(6) The teacher gave students time to think about what they had seen about texture and shape with the digital microscope as part of their art lesson on these topics (A-viii-A4-3);

(7) The teacher thought that the digital microscope encouraged students to use more scientific terms and to ‘capture’ exactly what they wanted to show in their art lessons (A-viii-A4-5);

(8) The teacher observed that the students learned to manipulate the art objects under the digital microscope and in that way attained a closer and closer view of the objects (A-viii-A4-1); and

(9) The teacher felt that it was important for the students to have time to ‘play’ or ‘mess’ with the digital microscope so that they understood better what the digital microscope was and what it could do in their art lessons (A-viii-P4-1).

In 2006, these responses addressed the second research question:

(1) The teacher thought that the digital microscope and the way it worked encouraged students to choose their own art objects to work with and to work at their own pace. The teacher also felt that the digital microscope helped students see the art objects more like the artist Georgia O’Keeffe did (A-viii-P6-1). And, the teacher encouraged students to share their findings and discoveries about art objects and this led to more student interaction and greater student insight (A-viii-P6-4);

(2) The teacher allowed students time to gain an understanding about how it feels to study something in detail using a microscope and the feeling gained by attaining

a deeper understanding of something in nature. In this regard, the teacher noted that students thought they knew what it felt like to be a scientist (A-viii-P6-2);

(3) The teacher used the computer monitors and the classroom's big screen to display images from digital microscopes during the art lessons. This allowed all students to share discoveries all at once and to engage in community discourse about their findings (A-viii-P6-3);

(4) The teacher taught art lessons using digital microscopy by encouraging students to spend time observing and discussing their findings (A-viii-P6-5);

(5) The teacher employed the social aspects of group learning to advance the art lessons using digital microscopy in inquiry (A-viii-A6-1);

(6) The teacher encouraged students to work as a group and to speak to each other and the teacher about what they were finding during the art lessons using digital microscopy (A-viii-A6-3);

(7) The teacher engaged the students in activities that might have started out differently, but were allowed to change into group activities for the art lessons (A-viii-A6-2);

(8) The teacher detected a strong sense of ownership of the art lesson, including its design, digital imagery, and finished products, coming from the students (A-viii-A6-2);

(9) After two years of use, the teacher still continued to allow students to direct their own art lessons using digital microscopy (A-viii-A6-5); and

(10) The teacher found that student familiarity with digital microscopy from use in other classes did not diminish their enthusiasm for using it in art lessons (A-viii-

A6-5) and the teacher felt the students' backgrounds in digital microscopy (from the enrichment class and other classes) helped improve the art lessons (A-viii-A6-4).

Teacher. The view of this participant teacher about teaching classes using digital microscopy, as revealed through the semantic domain category *teacher*, included the following results.

In 2004, these responses addressed the second research question:

(1) The teacher explained to the students who Georgia O'Keeffe was and how O'Keeffe saw flowers and shells as art objects. The teacher then used the digital microscope to help students focus on flowers and shells and see them up close and magnified as Georgia O'Keeffe did in her work (A-ix-P4-1). And, the teacher explored the art style of Georgia O'Keeffe with students and then gave them art lessons to complete in that style using the digital microscope (A-ix-A4-6);

(2) The teacher used the combination of the teacher's enjoyment of magnified art in general and the new views provided by digital microscopy to enhance the art lessons and convey excitement to the art students (A-ix-P4-2);

(3) The teacher found that the digital microscope worked so well with art lessons that the teacher planned to keep using it in the future and wanted to share with other teachers (A-ix-P4-3). The teacher thought that an important way to use the digital microscopes in education was to share them and the teacher's experiences with other teachers and get their ideas (A-ix-P4-5);

(4) As the teacher taught the digital microscope art lessons, the teacher monitored what the students were seeing and doing by looking at their computer monitors and the classroom's big screen, which could be connected to a selected computer

monitor. These displays allowed the teacher to see what the students were seeing at the same time that the students were seeing them throughout the lesson, which was a great help to the teacher in these digital microscope-based art lessons (A-ix-P4-4);

(5) The teacher used the digital images made by students to make high-quality prints for students to study and use for sketching, drawing, and painting in the art classroom (A-ix-A4-1);

(6) The teacher modified the art lesson plan to accommodate the high level of student interest and the fact that students did not want to stop working on the digital microscope-based art lesson. The teacher had to allow more time in the lesson and change the lesson's plan so that students could do their art work in the computer laboratory (where the digital microscopes were located) rather than return to the art classroom to do their sketching (A-ix-A4-2);

(7) The teacher noted that the art lessons using digital microscopy worked best when the students were given time to explore using the equipment. The teacher noted that the results of the art lessons were much better than any other method used in the past and this encouraged the teacher to continue using the digital microscopes in art lessons (A-ix-A4-3);

(8) The teacher was excited about the results of digital microscope-based art lessons and wanted to share that excitement with all the students and other teachers at the elementary school (A-ix-A4-4); and

(9) After the initial scientist-teacher partnership began, the teacher subsequently wanted to help form a 'team of teachers' to share ideas and look at new ways to use the digital microscope (A-ix-P4-3). And, the teacher subsequently wanted to

share ideas with other teachers and look at new ways to use the digital microscope (A-ix-P4-5).

In 2006, these responses addressed the second research question:

(1) The teacher continued to allow students to have extra exploration time with the digital microscope and then work on their lessons (A-ix-P6-1);

(2) The teacher felt that the students should handle and feel the art objects in addition to looking at them closely under magnification while using the digital microscope. The teacher thought that touching the objects helped students better understand their nature (A-ix-A6-2);

(3) The teacher was so pleased with the art lesson using digital microscopy that the teacher wanted to reach out to other teachers with the results and to share imagery on a class web-page (A-ix-P6-2);

(4) The teacher thought that the digital microscope allowed the teacher to see in new ways, including seeing as the students see, seeing as the digital microscope 'sees,' and seeing as Georgia O'Keeffe saw (A-ix-P6-3);

(5) The teacher felt that the more students used the digital microscope the more effective would be instruction during art lessons, which actually evolved into inquiry lessons (A-ix-P6-4);

(6) The teacher noted that the teacher might use digital microscopy in some of the teacher's own art work and in more student art lessons in the future (A-ix-A6-1); and

(7) The teacher wanted to share ideas with other teachers and look with them at new ways to use the digital microscope. Also, the teacher subsequently wanted to form

a partnership with students in building a class web-page to share digital imagery from the art lessons (A-ix-P6-2).

Summary of the second research question. The participant teacher's way of teaching art classes using digital microscopy was affected by the digital microscope's *characteristics*, which encouraged individual exploration and inquiry, allowed exploration of art objects and materials, permitted students to work together and with the teacher in lessons, allowed students to eventually direct their own explorations, permitted students to place light where they wanted it and to make images and imagery for later use, showed what students were interested in and wanted to see, gave the students software to enhance digital images, and promoted open-ended lessons.

In *comparison* to other methods used in art lessons of the past, the digital microscope gave students the close-up, limited view of art objects, such as the flower, that mimicked the art style of Georgia O'Keeffe and allowed students to get close to objects, like a flower, without crushing it. In *connecting* with aspects of art and other areas, the digital microscope helped students relate to art materials, the art-science relationship, art styles like Georgia O'Keeffe's and styles of lighting in art, other students in discourse about art, and with writing and other curriculum areas covered by state standards. The teacher observed that students wanted to look first at their own eyes, hair, etc., and when they moved on to the art lessons they looked at art materials, art objects (flowers, shells, etc.), and things brought in from outside.

In *seeing*, the teacher allowed the students to spend time looking at the properties of objects and to develop a fascination for the microscopic world. Then, students studied art objects in lab and made digital images that were studied again in the classroom for drawing and painting lessons. Seeing brought out the students appreciation for shape, color, and texture, the basic elements of art, which helped the students gain an artist's view of these things though the digital microscope.

The teacher noted that *students* especially liked to choose their own objects for study and that they exhibited a strong sense of ownership of their images and results. The students wanted to work as a group and were amazed at what they were seeing. Being able to see all computer monitors at once and therefore knowing what others were finding, the students continually learned from each other and spontaneously discussed and gestured about what they were finding with the digital microscope. The students maintained a high interest level in digital microscopy lessons and the lessons captured their imaginations. The teacher found that students wanted time to think about the lessons. The students learned to see more like Georgia O'Keeffe and better appreciated her art.

The *teacher* conveyed a personal enjoyment of art and the art style of Georgia O'Keeffe to the students and they responded with an enthusiastic acceptance of the digital microscope as an art tool. The teacher was pleased with the art lessons using digital microscopy saying superior results were achieved and this caused the teacher to want to share the digital microscope experience with other teachers and to consider a class web-page on digital imagery. The teacher thought that being able to see all students' progress (via the computer monitors) was an important facet of these successful lessons. Also, the teacher thought that the digital microscope could be used in some of the teacher's own personal art work in the future and that a class web-page could be set up to share imagery and ideas.

Conclusion for the second research question. The digital microscope, computer monitors, and the digital images and prints from those images affected the teacher's way of teaching art in lessons using this equipment. These changes included the way that the teacher planned the art lessons and the way that the teacher allowed the lessons to evolve from strictly art lessons to art inquiry lessons. Also, the way that the teacher observed the lesson and what the students were doing changed because of the computer monitors. The teacher found that the digital microscope particularly helped students connect with the art style of Georgia O'Keeffe, an important figure in art for this teacher. The remarks of this teacher over the period 2004-2006 suggested that there was potentially a long-term change in the way of instruction of some art lessons, which centered on using digital microscopy.

Third Research Question

How does the introduction of the digital microscope into classrooms affect the way that the participant teachers view student learning using digital microscopy? Responses to this question were revealed through several semantic domain categories, as described below.

Characteristic. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *characteristic*, included the following results.

In 2004, the teacher noted that students used the special features of the digital microscope to explore and that student exploration drove the students' lessons, especially during the time that they were becoming accustomed to using the digital microscope (A-i-P4-1).

The teacher found that the students adapted well to using the child-friendly aspects of the digital microscope, so the teacher encouraged the students to learn about what the digital microscope could do for them in art lessons by exploring (A-i-P4-4).

The teacher found that the digital microscope's characteristics encouraged student curiosity and the desire to look at objects up close, which the teacher felt was starting to drive the art lessons (and the teacher encouraged this) (A-i-P4-5).

As a result of the digital microscope, the teacher felt that students were more focused on what they wanted to see during art lessons. The students focused more on these objects than with the simple artist's view finder because of the new technology (A-i-A4-1).

In 2006, because of the engaging nature of the digital microscope, the teacher found that the students enjoyed their art lessons more and learned more, which tended to make the art lessons more open-ended (A-i-P6-2). The teacher found that the students were natural explorers using the digital microscope and encouraged their exploration and sharing among themselves during inquiry (A-i-P6-3).

The teacher felt that the students were drawn into the lessons by the visual appeal of the digital microscope and what it showed the students. The teacher thought that student learning was enhanced by this visual appeal (A-i-A6-2).

Comparison. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *comparison*, included the following results.

In 2004, the teacher found that students were better able to focus on selected parts of a larger object using digital microscopy in art lessons than by using some other method. In the past, looking closer meant that students would place the object nearer their own eye (A-ii-A4-1). However, using the digital microscope allowed them to see parts closer on a computer monitor where it was easier to observe (A-ii-P4-1).

In 2006, the teacher felt that the students could better understand the close-up view of the Georgia O'Keeffe style of art when they used the digital microscope in the art lessons with fresh flowers as compared to lessons in previous years when the students used an artist's view finder or a magnifying glass (A-ii-P6-1).

Connection. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *connection*, included the following results.

In 2004, the teacher noted that students saw the connection between art and science in the digital imagery they made of natural objects, especially flowers (A-iv-P4-2). The teacher also thought that art lessons with the digital microscope allowed students to form a connection between the more complete picture of an object (as in the human eye view) and the limited area that they were seeing with the digital microscope (A-iv-A4-1).

The teacher felt that the students were able to connect with some types of modern art by using the manipulative aspects of the digital microscope and also moving the art objects in order to achieve special lighting effects (A-iv-A4-2). The teacher felt that students achieved a new perspective of ordinary objects by using lighting and perspective in order to connect the art lessons to the art style of Georgia O'Keeffe (A-iv-A4-3).

In 2006, the teacher noted that students used the digital microscope to connect to the art of nature up-close and that they wanted to write about what they were seeing. The teacher encouraged them to do so and to connect with the natural art of Georgia O'Keeffe and her style of art (A-iv-P6-1). The teacher found that the students were easily drawn into the view of the artist Georgia O'Keeffe because of the way that the digital microscope focused on parts of the flowers and shells that they were studying (A-iv-A6-3).

The teacher found that the students viewed art differently and they viewed science differently after seeing how they were closely connected during digital microscope-based art lessons (A-iv-A6-2).

Knowing, object, and seeing. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *knowing, object, and seeing*, included the following results.

In 2004, the teacher found that students naturally wanted to show that they understood the concepts better by interacting verbally — and then by drawing and writing — during and after the art lessons with digital microscopy (A-v-P4-1).

The teacher found that the students wanted to first see their own features (faces, eyes, hands, etc.) with the digital microscope and then move on to other things, including art objects such as flowers, shells, etc. (A-vi-P4-1).

The teacher was informed by the students of their natural fascination with the hidden world, as revealed by digital microscopy, and their desire to look closer and closer at art objects (A-vii-P4-1). The teacher found that the students looked close, closer, and even closer at art objects during digital microscopy sessions and again at the digital images they had made during lessons in the art classroom (A-vii-A4-1). And, the teacher noted in the way that students viewed objects and in their digital imagery that they were seeing closer and closer the fine details and textures of art objects in the lessons (A-vii-A4-2).

The teacher found that students were fascinated with the art objects seen during digital microscopy and later were insightful about the digital images they made, which were used in classroom art lessons on sketching, drawing, and painting (A-vii-P4-1). And, the teacher found that students were seeing art objects in a new way by using digital microscopy and this helped them achieve desired results in art lessons (A-vii-P4-2).

Regarding the artistic style of Georgia O'Keeffe, the teacher felt that the students saw the true artistic view of seeing closer and closer using the digital microscope in lessons with flowers and shells (A-vii-A4-2).

In 2006, the teacher found that the students had a different, metacognitive view of art materials after seeing them under the digital microscope and thinking about their experiences (A-vii-A6-1).

The teacher felt that students being allowed to bring in art objects from outside the classroom added to the learning experience of the lessons (A-vi-P6-1).

The teacher noticed that students were fascinated by the unusual and engaged that fascination when asking students to look more and more closely at the art objects using digital microscopy (A-vii-P6-1). And, the teacher found that students learned about art by seeing an artist's point of view (like Georgia O'Keeffe's) through the digital microscope (A-vii-P6-2).

The teacher discovered that the students looked close, closer, and even closer at things that fascinated them, including things that were unexpected to them (A-vii-P6-1).

And, students saw closer and closer as they used the digital microscope and the images they made to look into the hidden meaning of art objects (A-vii-A6-1).

Students. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *students*, included the following results.

In 2004, the teacher felt that students preferred to work in groups rather than in pairs and that they wanted to interact with each other continually through the art lesson sharing what they were seeing and discovering (A-viii-P4-1). The teacher found that the students worked very well in a group as they focused on the elements of art that interested them and were part of the lesson (A-viii-A4-2). And, the teacher found that students learned best in the digital microscope art lessons by being in an environment (i.e., the classroom community) where they could discuss and share findings and observations (A-viii-A4-1).

Other teacher observations included:

(1) The teacher found that students learned a lot by ‘just playing’ or ‘messing’ with the digital microscope in preparation for their art lessons (A-viii-P4-1);

(2) The teacher found that the students needed time to think and reflect on the art lesson in order to better understand what they had seen about texture and shape using the digital microscope (A-viii-A4-3);

(3) The teacher felt that the students needed to ‘keep an eye on what other students were doing’ during the art lessons using digital microscopy. The teacher felt that this was an important aspect of student learning in this kind of at lesson (A-viii-A4-4);

(4) The teacher found that the students used more scientific terms and captured exactly what they wanted to show using digital microscopy during art lessons (A-viii-A4-5);

(5) The teacher felt that students wanted to see the object first and then look at it under increasing magnification to help understand what they were seeing (A-viii-A4-1); and

(6) The teacher thought that the students' being able to capture digital images with the digital microscope allowed students to see in a new way and look more closely at art objects (A-viii-A4-5).

In 2006, these responses addressed the third research question:

(1) The teacher found that students preferred to pick and choose what they wanted to work with and work at their own pace (A-viii-P6-1);

(2) The teacher found that students had feelings about what they were studying and how they were studying using the digital microscope. The feelings had to do with a deeper understanding of what it was like to study something in detail and know it better. Also, the feelings had to do with what it was like to be a scientist (A-viii-P6-2);

(3) The teacher found that students liked to share their findings during the art lessons by talking and pointing to and looking at the computer monitors and the classroom's big display screen (A-viii-P6-3);

(4) The teacher felt that student learning was enhanced (insight was gained) by student interaction (sharing) during the lesson (P6-4). And, the teacher thought that students learned by observing and listening to other students during the art lesson using digital microscopy (A-viii-P6-5);

(5) The teacher found that students understood the magnified art objects better if they also handled and felt the objects before and during their study with the digital microscope (A-viii-A6-2).

(6) The teacher found that all students had a high level of interest in art activities using digital microscopy and there were no gender differences noted (A-viii-A4-6);

(7) The teacher viewed student learning as a group activity in which all students were immersed and engaged all the time. The students' continual sharing of discoveries and their constant discourse informed the teacher of their high level of interest and engagement (A-viii-A6-1);

(8) The teacher found that students 'each wanted a turn' even though they preferred to work as a group on the art lessons using digital microscopy (A-viii-A6-2). And, the teacher found that students made many discoveries and that they alerted their classmates to those discoveries by making verbal announcements such as saying 'wow' and 'hey' with an invitation to come over to see what was found (A-viii-A6-3);

(9) The teacher felt that students were now coming in with a background in digital microscopy (versus students in 2004) and that this helped the art lessons. The teacher noted that students were more familiar with the digital microscopes now (versus 2004) yet the students were as excited as before with what they were seeing (but not so much impressed with the equipment) (A-viii-A6-4). However, this familiarity did not diminish their enthusiasm for the art lessons using this equipment (A-viii-A6-5);

(10) The teacher noted that as students examined the art objects in the way that Georgia O'Keeffe would have, they were drawn in to looking closer and closer at the objects in order to better understand their structure (A-viii-P6-1); and

(11) The teacher was informed about how students see close, closer, and even closer by listening to their discourse and watching their interactions as they observed the digital microscope images being displayed on the computer monitors in the classroom and the big screen at the front of the classroom (A-viii-P6-3). The teacher commented that as the object was enlarged more and more, it became more and more abstract to the students (A-viii-P6-5). As the lessons progressed, the students spoke up and informed each other and the teacher about what they were seeing as they looked close, closer, and even closer at art objects (A-viii-A6-3).

Teacher. The view of this participant teacher about student learning using digital microscopy, as revealed through the semantic domain category *teacher*, included the following results.

In 2004, the teacher made observations about feelings and perceptions of the teacher (what the teacher view was of student learning using digital microscopy), including:

(1) The teacher viewed student learning in a different way after seeing how they work and make discoveries as a group. This was possible by looking at all computer monitors and the big screen and participating with students in the digital microscope art lessons (A-ix-P4-4);

(2) The teacher found that there needed to be as many digital microscopes as possible in the classroom for all the students to get access in order to complete their lessons (A-ix-P4-5);

(3) The teacher viewed student learning as remarkable in that the students rapidly learned to reproduce the art style of Georgia O'Keeffe using the digital microscope and its digital imaging functions (A-ix-A4-1; A4-6).

(4) The teacher accommodated the students' requests for more time to explore using the digital microscope as they worked on their art lessons (A-ix-A4-3). And, the teacher viewed the level of student engagement with surprise when the students did not want to stop working on the art lessons using digital microscopy (A-ix-A4-2);

(5) The teacher was excited by the results of the art lessons, especially the prints of digital images showing art objects, which were taken by students using the digital microscope (A-ix-A4-4); and

(6) The teacher found that because students liked to be independent in their choices of materials to examine when given a group of art objects to choose from, their work was much more thorough than expected (A-ix-A4-5).

In 2006, the teacher felt that because students were receptive to sharing digital microscope imagery on a class web-page, they might establish such a class web-page (A-ix-P6-2).

Based on what the teacher perceived as the great success of the digital microscopy project, the teacher subsequently wanted to share ideas with other teachers and look with them at new ways to set up the classroom for digital microscopy and to store digital information (A-ix-P6-5).

Summary of the third research question. The teacher's view of student learning using digital microscopy was affected by the digital microscope's *characteristics*, which encouraged exploration, curiosity, and enjoyment in the art lessons. The teacher noted that students were natural explorers and that the digital microscope with its child-friendly nature and visual appeal, brought this out in students. *Compared* to the artist's view finder or the magnifying glass, the digital microscope was better able to focus the students' view on small parts of a larger object, particularly helping students grasp the art style of Georgia O'Keeffe. In the past, when the teacher stated 'look closer' the students held objects near their eyes, but with digital microscopy they hd the closer view without holding the object.

The *connection* between art and science emerged for the students, especially when looking at flowers. In the art lessons using digital microscopy, students saw the connection between the larger (macroscopic) view from the human eye and the microscopic view on the computer screen and this caused them to now look at objects differently. The students also saw connections to modern art (perspective and lighting) and the art of nature as in O'Keeffe's work.

At first, students wanted to see their own faces, hair, etc., but later settled in to work with art objects. Once they studied these *objects*, they wanted to draw and paint them and then write about them. There was a natural fascination with the microscopic world and this stimulated insightful sketches and drawings. Through metacognition, the students created art reflecting on what they had seen with the digital microscope. Objects from outside the classroom and unusual objects tended to stimulate more interest and curiosity during inquiry.

During art lessons using digital microscopy, the *students* strongly preferred to work as a group in which there was continual interaction (talking and pointing), vigorous discussion of findings, sharing findings via the computer monitors and big screen, and constant watching of what others were doing and seeing. Even though this was a group activity (a classroom learning community), each student wanted his or her own turn at the digital microscope. Student learning and gaining insight was a group activity. Students would alert each other about discoveries by saying ‘wow’ or ‘hey,’ which invited other students to look. Also, students needed time to reflect on what they had seen and they developed feelings about what they studied, which showed a deeper understanding of the lessons and brought out scientific conceptions of themselves.

The *teacher* mentioned that having all the computer monitors visible during the art lessons using digital microscopy presented a new and much improved way to teach art lessons. The teacher was excited about the class working as a group and so readily adapting to the art style of Georgia O’Keeffe. Also, the teacher expressed excitement about the results of all art lessons using digital microscopy and was surprised when students asked for more time with art lessons and did not want to stop using the digital microscope. The teacher was especially pleased with the prints of students’ digital images and how well they worked in the art classroom for drawing and sketching activities. The teacher wanted to share the digital microscope with other teachers and wanted to work on a class web-page with digital imagery.

Conclusion for the third research question. Using the digital microscope, including the computer monitors and digital imagery and prints from those images, affected the teacher’s view of student learning during lessons involving this equipment.

These changes included the way that the digital microscope allowed the ‘natural explorer’ in the students to come out and change the art lessons. With the teacher’s guidance, the students took more time, worked naturally as a group, engaged in exploration and discovery, shared their findings, and expressed themselves during the lessons. The computer monitors changed the way that the students observed what was happening during the art lesson. The teacher was excited about the results of the art lessons and wanted to share this excitement with other teachers and was considering a class web-page to share digital imagery. The observations of this teacher over the period 2004-2006 about what the teacher viewed as the overall success of using digital microscopy in art lessons suggested that there was a change in the way that the teacher viewed student learning during art lessons that involved digital microscopy.

Results

This section is divided into two parts: Summary and Discussion and Conclusions and Implications.

Summary and Discussion

In this study, the introduction of the digital microscope into the elementary classrooms began in 2004 with two participant teachers. The participant teachers were an enrichment and an art teacher, Teacher E and A, respectively. The central question was: “*How does the introduction of the digital microscope into elementary (K-5) enrichment and art classrooms affect what teachers say and do?*” In continuing to address that question, the following summary and discussion relates the results and findings of this study to pertinent concepts in educational literature.

Collaboration and Partnership

Initially, both teachers were in a newly formed collaboration with a university scientist, who initiated the grant program that brought the digital microscopes and related computer equipment to the elementary school. That scientist-teacher collaboration continued over the course of the study; however the teachers formed a partnership with their respective students as they implemented new lessons each year.

Gosselin et al. (2003) used the term collaboration to mean that there was a "working relationship (of professionals) … in order to accomplish a goal that they share" (Gosselin, 2003, p. 118). They noted that the characteristics of effective collaboration are: voluntary participation; a parity basis; shared goals; shared responsibility; shared accountability; shared resources; and emergent ideas. All the above characteristics, to one degree or another, apply to the scientist-teacher collaboration as described by both teachers.

Partnership was described by Marek (2002) as a symbiosis, where each entity gained greatly through the symbiosis. Partnership was a style of collaboration and might include: scientist-teacher(s) (Gosselin et al., 2003; Harnik & Ross, 2003), teacher-students (Cornell, 1998; Liem, 1987), student(s)-scientist (Barab & Hay, 2001; Lawless & Rock, 1998); or students-scientist-teacher(s) relationships (Ledley et al., 2003; Rahm et al., 2003). In this instance, the partnership was between teacher and students.

With both teachers, partnerships with their students developed naturally as the respective enrichment and art lessons evolved from routine lessons (where digital microscopy was introduced) into more authentic, inquiry-based lessons.

Authentic Inquiry

In describing their enrichment and art lessons, respectively, Teachers E and A mentioned that the hands-on lessons involving digital microscopy led in new directions, became more student-driven, and resulted in student work products that were outstanding and original. Both teachers noted that digital microscope lessons went in directions that they could not have anticipated ('a lot of it was accidental'), while still yielding superior results ('beyond anyone's expectations' and 'never this good on this level').

Rahm et al. (2003) defined *authentic science* as an emergent property that was the direct result of interactions among students, teachers, and scientists within partnerships. Rahm et al. (2003) noted that authentic science was a way of engaging students and teachers that went beyond static science classroom learning and that authentic science emerged rather than having been outlined beforehand, as in a textbook or laboratory manual. Based on the similarities of descriptions of enrichment and art inquiry activities using digital microscopy, the term *authentic science* could be modified in this instance to *authentic inquiry*.

Lawless and Rock (1998) pointed out that there was a parallel arrangement of steps in the scientific method of inquiry and important educational objectives in the science inquiry classroom. As just noted, in this study, enrichment (science, social studies, mathematics, language, and writing) and art activities were quite similar in their approaches to lessons that employed digital microscopy. For example, Teacher E's activities with insects and crystals using digital microscopy were quite similar to the same teacher's activities with coins and currency. In turn, Teacher A's art activities were quite similar to Teacher E's activities.

One of the main effects of authentic inquiry, as related by many authors, was the students' sense of ownership of ideas, discoveries, and work products. For example, Barab and Hay (2001), in describing these effects, noted that a sense of ownership might be achieved by the students that was especially important to them because of the wide perception that only professional researchers and textbooks possessed new information. They also described a social aspect of the sense of ownership, namely a sense of identity as a member of a community, which was also a strong positive motivation for students in the inquiry process.

Both teachers remarked on the sense of ownership and the social aspects of inquiry, which were key elements making routine lessons into more student-driven inquiries. During inquiry activities of both teachers, their respective students wanted to bring in objects for study with the digital microscope and both teachers accommodated these requests. Both teachers commented that students were enthusiastic about their work and wanted to save it, show it to other students, and take it home with them. Teacher E remarked that 'they take that picture and it is *theirs*,' and the teacher recounted that one student stated 'I'm taking this home to my dad!'

Inquiry-based lessons arising from collaborations and partnerships helped students and teachers to achieve the objectives such as the National Science Education Standards (National Academy of Sciences, 1995; National Research Council, 1996; TERC and The Concord Consortium, 1996; National Research Council, 2000) and state and local standards as well. Both teachers remarked on how the inquiry lessons helped them achieve educational standards in their respective curriculum areas, including interdisciplinary connections and technology applications, as well as bringing out higher level thinking skills and requiring student decision-making. Teacher E spoke about connections to writing, mathematics (geometry and measurements), social studies, technology (computers), geography, ethics and law (copyright and counterfeiting) and other topics, whereas Teacher A mentioned connections to music, reading, writing, technology, and the sciences. Both teachers developed innovative new lessons using digital microscopy that connected with parts of their standard curriculum. For example, Teacher E used digital microscopy of U.S. currency to connect with history and social studies and Teacher A used digital microscopy to experience the art style of Georgia O'Keeffe. Both teachers mentioned each others' work with the digital microscope and that other teachers were interested in the digital microscope in their own classes. Further, both teachers mentioned the possibility of constructing web-pages where digital images and videos of their students' work could be archived and shared with other teachers, students' parents, and other students.

Pedagogy in the Inquiry Classroom

Communication

In discussing communication in the classroom, Pea (1994) remarked that "students are not blank slates written on with curricular lessons, [but rather] they are active learners who have … developed substantial beliefs and ways of thinking before ever coming to school" (Pea, 1994, p. 289). In Pea's transformative communication, teachers would make a significant effort to "understand what students are thinking" and themselves may "develop new understandings of the subject domain by seeing how students … think about it" (Pea, 1994, p. 290).

Both teachers used transformative communications in their respective lessons using digital microscopy. The inquiry lessons of both teachers evolved from more traditional to transformative as each teacher became essentially a partner and participant along with their respective students. Both teachers started their lessons as structured assignments, especially at the outset of the study, but the lessons changed and each teacher joined in with the students during the lesson. Both teachers had conducted lessons on the same topics in the past, but without the aid of digital microscopy. By each teacher's own account, digital microscopy transformed the lessons mainly because the teacher and students could see magnified details together and all at the same time. Both teachers made comments like this: 'everyone could see everyone's computer monitors all at the same time' and 'I could see what all the students were also seeing.'

How People Learn

Donovan et al. (1998), writing in the U.S. Department of Education-sponsored volume titled *How People Learn, Bridging Research and Practice*, made the following observations about inquiry-based teaching: (1) "Teachers must draw out and work with the pre-existing understanding that their students bring with them;" (2) "Teachers must teach some subject matter in depth, providing many examples in which the same concept is at work and providing a firm foundation (of) actual knowledge;" and (3) "The teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas" (Donovan et al., 1998, p. 8).

Both teachers remarked on the need to draw on pre-existing understandings to help scaffold learning during inquiry lessons using digital microscopy. Both teachers noted that these pre-existing understandings came from other classes, student experience with computers and cameras at home and at school, programs seen on television, and the students' own life experiences. Further, both teachers taught their subject matter in depth prior to the inquiry lessons and then used students' metacognitive skills in integrating a variety of subjects into inquiry-based digital microscope lessons. Regarding metacognitive processes, both teachers remarked that it was important to give students *time to think* about what they were seeing and doing in the digital microscopy lessons and to give them additional time to do their inquiry lessons because of the discoveries and connections that students were making on their own.

Constructivism

Constructivism, or the idea that students actively construct knowledge and that knowledge emerges from inquiry, has a long tradition in educational philosophy including the classic works of Piaget (reviewed by Bosak, 1991; Crowther, 1999; Krampen, 1991; Phillips, 1994) and Vygotsky (reviewed by Shapiro, 1994).

Jean Piaget (1896-1980) studied how children's minds develop and wrote about how children spontaneously respond to new ideas about the physical world around them (Bosak, 1991). Piagetian theory holds that students do not learn entirely from doing, but rather they learned more from "thinking about what they are doing" (Bosak, 1991, p. 7). In this view, students passed through sequential stages according to being "operational" (Bosak, 1991, p. 7), or being able to move back and forth through steps in a scientific process (Phillips, 1994).

Lev Vygotsky (1896–1934) studied how children constructed meaning and held a contrasting view that the "formal presentation of scientific ideas in school contrasts with the child's approach to ideas about phenomena" (Shapiro, 1994, p. 35). Shapiro (1994) noted how Vygotsky distinguished nonspontaneous from spontaneous ideas, a distinction between ideas learned from books versus ideas arrived at by experience, respectively. In Vygotskian education, the student constructed connections between nonspontaneous and spontaneous in the classroom. Bouillion and Gomez (2001), referring particularly to the classic concepts of Vygotsky, remarked that "learning is mediated by highly articulated tasks and activities in the social contexts of day-to-day living" (Bouillion & Gomez, 2001, p. 878). They noted the "patterns of activity from school often do not fit the more articulated activities that children observe or in which they participate (outside of) school" (Bouillion & Gomez, 2001, p. 879), and further noted that "this disconnect can lead learners to perceive school learning as separate from life learning." Their thesis was that a scaffolding, or bridge connecting the real world and real learning, must exist in order for students to see any topic, for example – science, as meaningful and relevant.

In the evolving approaches of both teachers, one can see both Piagetian and Vygotsky-type perspectives. Especially in the early part of the study, both teachers remarked on 'connecting' (scaffolding) from book-learning and non-school experiences to the digital microscope inquiry lessons and 'piggy-backing' of learning. However, with time both teachers adopted an inquiry strategy of allowing students to direct their own lessons and have more time and to think more about what they were doing and therefore let student interest drive the inquiry lessons. Both teachers mentioned behavior that was in fact operational learning ('connections flowing back and forth') in the digital microscope lessons and both remarked on how students did not want to stop using the digital microscope when the lessons were supposed to end. Both teachers discussed the computer and digital camera connection and how that made sense to the students (via scaffolding) because most students had used computers, their software, and digital cameras prior to using the digital microscope for the first time during enrichment and art inquiry lessons.

Modern constructivist education, i.e., learning that involved knowledge “actively constructed by the individual (student) based on his or her prior knowledge rather than being added on or accumulated from new information” (Chang et al., 1999, p. 331), had become widespread over the past few decades. Crowther (1997) defined modern constructivist education, saying “as we experience something new, we internalize it through our past experiences or knowledge constructs” (p. 2). This included the idea that “meaning is constructed by the cognitive apparatus of the learner” (p. 3). Crowther described the modern constructivist classroom as one where there was “active cognitive involvement,” “thinking out loud,” and activities in small groups that provided “expanded opportunities for cognitive restructuring” (p. 6) and a strong assessment of what students were doing.

In enrichment lessons, Teacher E used insects, crystals, coins, and currency as the focus of inquiry lessons. In art lessons, Teacher A used flowers, shells, and art objects as the focus for inquiry lessons. By their own accounts, both teachers described students thinking out loud. For example, during discourse about an insect inquiry lesson, a student of Teacher E remarked about the bee’s stinger, ‘that’s why it hurts.’ In another instance, a student made the connection about the thirteen original colonies and the repeating pattern of thirteen symbolic items on some U.S. currency. Of such metacognitive observations, Teacher E remarked that ‘all of a sudden, it made sense to them.’ In a similar moment, Teacher A noted that a student remarked ‘wow, that’s a flower!’ It was notable that both enrichment (including science and non-science lessons) and art activities were very similar in their student discourse and discovery that included a science-art and an art-science connection.

Discrepant Events

Teaching and learning through encounters with discrepant events was commonly used in inquiry-based classrooms (Appleton, 1996; Friedl, 1997; Liem, 1987). In discrepant event learning, students encountered something unexpected, an unanticipated outcome, or something occurred that contradicted the student's preconceptions (Appleton, 1996; Liem, 1987). Appleton (1996) referred to this phenomenon as cognitive conflict, which was based on the Piagetian idea of disequilibrium. Appleton (1996) gave three ways that inquiry classroom teachers might typically respond to discrepant events encountered during inquiry: (1) the teacher offered an explanation, which was accepted by students; (2) students asked questions and verbally explored hypotheses, which involved student discourse; or (3) students engaged in exploration, which involved student discourse with the teacher structuring the inquiry.

Both teachers made use of discrepant events in digital microscope lessons mainly because the nature of looking at objects under magnification presented students with many instances where an explanation was needed to understand what was seen. As Teacher E expressed the students' dilemma saying 'looking up close at the object does not look like it did originally.' Both teachers reported that students asked them for explanations, explored hypotheses through discourse among themselves, and engaged in exploration. When asked questions during lessons, both teachers noted they usually responded with questions ('why do you suppose that is?'). In one instance, Teacher A referred to discrepant events as ‘brain teasers’ and remarked that ‘working with brain teasers was fun.’ According to the teachers, it did not matter that the inquiry lesson was on art objects, coins and currency (social studies), or insects or crystals (science), the student response was essentially the same regarding the nature and value of discrepant events. Discourse and further investigation was initiated among the students, which was the main goal of the inquiry lesson.

Learning Environments

In *Shaping the Future: Strategies for Revitalizing Undergraduate Education*, Lane (1996b) stated that “the most effective teaching methods emphasize student learning in active, collaborative settings” (Lane, 1996b, p. 6). Jones et al. (2000) noted that it was important for students to have access to *tools for inquiry* and to be able to make choices about tools when engaging in classroom-based scientific investigations. They referred to tool space as equal in importance to conversation space (i.e., time and a place to talk) in active inquiry and listed the three characteristics of tool space as “access to tools, desire to use tools, and competition for tools” (Jones et al., 2000, p. 763). Social position and social dynamics of the group could limit an individual student’s use of tools (Jones et al., 2000). Similarly, Herrenkohl and Guerra (1998) found that the small group aspect of elementary collaborative investigation was very important. They described how small groups of fourth graders were generating, supporting, and building knowledge and understanding in active learning situations.

Roth (1996b) also studied tool use and what he called knowledge diffusion among elementary students. These elementary classrooms were “transformed as a tool (glue gun) and associated practices came to be shared by the members of the classroom community”

(Roth, 1996b, p. 179). He reported that the social community, which was studying a unit on civil engineering, was transformed as students with "peripheral participation" entered full participation as the "newcomers learning at the elbows of their more competent peers" (Roth, 1996b, p. 179). In Roth's view, the ease with which "student-centered adoption" of the new tool was accounted for by "actor network theory" (Roth, 1996b, p. 179), a way of understanding classroom behavior according to observed causes and effects and how actors interact with one another by talking and gesturing. Roth (1996b) hypothesized that cognition was the result of the interaction of a task, an individual, and the physical and social setting, and he remarked that "individual (students) move along trajectories from being newcomers to becoming old-timers" within a classroom community (Roth, 1996b, p. 179). Roth went on to say that the effect with a classroom community of new tool technology was "indeterminate in that it cannot be predicted" with much certainty (Roth, 1996b, p. 212).

In this study, tool use referred to the digital microscope, which similarly transformed the respective classroom during enrichment and art lessons, as recounted by both teachers. As Teacher A noted, 'just the exposure to the new tool' changed the lessons. Both teachers noted that 'all students wanted a turn' using the digital microscope and that the students wanted to 'work as a group' and that they 'really like to share discoveries and ideas' during inquiry lessons. Both teachers remarked about social discourse in the classroom during lessons and how the students wanted to see what others were finding as the group (what Roth would call the 'community of practice') worked on the inquiry lessons. Both teachers found that it was unpredictable what students would discover during lessons and that is was similarly unpredictable what would particularly interest the students. Also, both teachers remarked that their students wanted to pursue inquiry in their own way and did not want to stop working when lessons were to end. In short, the transformative tool use, social aspects of the inquiry classroom community, the unpredictable nature of the effects of the new tool, and various student trajectories of learning were all recounted by both teachers in their remarks. It should be noted that Roth (1996b) reported on an elementary civil engineering lesson, yet essentially the same effects were noted in this study on elementary enrichment (science and non-science activities) and art lessons.

White and Frederiksen (1998), Pearce (1999), and Costa (2001) suggested teachers should continually emphasize a metacognitive approach during the inquiry process. They noted that the metacognitive approach could be broken down into two parts: the inquiry cycle and the reflective assessment. The former generally starts with a question, which led to some prediction, and this was followed by experimentation, model development, and application of the model (leading to more questions, thus completing the cycle). The latter (reflective assessment) allowed students to develop a potentially deeper understanding of inquiry and phases of the inquiry cycle.

Both teachers remarked on the effectiveness of the metacognitive approach, which they progressively used more in the inquiry lessons as a response to what the students told them that they wanted to do. Both teachers noted that students wanted (asked for) and needed time to think about what they were observing in the lesson. Both teachers found that allowing students to have more time for the lessons with digital microscope, including time for reflection on what they were finding, and allowing students to make cognitive connections and to some extent direct their own investigations (with teacher guidance) was particularly effective in achieving unexpectedly good results from lessons that had not worked well in the past with other tools or methods in the place of digital microscopes.

Student Behavior

Roth and McGinn (1998, p. 216) remarked that authentic inquiry lessons involved "problem posing, problem solving, and persuading peers." They also pointed out that learning environments typically did not take into account the central role of visual representations in inquiry. They discussed *inscriptions*, which they defined broadly as visual representations of nature, noting that scientists and engineers constantly engaged inscriptions, and suggested so too should an inquiry classroom. Inscriptions, served as means to engage others in thought and conversation, focused others' attention, and coordinated and constrained activities and conversations.

In this study, inscriptions are the digital images and videos made by students using the digital microscope and the digital representations that appeared in real-time on the computer monitors seen by the students during the lessons. In some art lessons, inscriptions also included drawings and paintings made from the digital images. These visual representations of nature (and in some instance, of man-made objects) engaged students in discourse, which was mentioned many times by both teachers. Without this capability to make such inscriptions instantaneously, the effect of digital microscopy would not be like that reported here.

Roth (1994) expressed the view that students communicated their findings in an inquiry-based classroom in much the same way that scientists communicated in their work as long as they were allowed to do so. He pointed out three communicative elements, “hands, eyes, and signs” (Roth, 1994, p. 170), and noted their interdependence in classroom communities of learning. He stated that students in the inquiry classroom community would naturally engage in communication when working together, a significant amount of which is *non-verbal*. Roth (1994) examined the effect of a “representational device,” in his study a chalkboard, saying “when all participants had access to the representational device … efficient communication occurred … in a way that is characteristic of talk in a scientific laboratory” (p. 180). In a subsequent study, Roth (1999) remarked that materials, gestures, and bodily movements all play a role in the “emergence of students’ science-related discourses” (p. 27), which expressed his thesis that more than just what students *say* is important in their learning interactions in the inquiry classroom. Later, Roth (2003) noted that student communications while in the presence of the material to be studied, had an important cognitive function and that gesturing, acting, talking, and making graphic representations helped form a “scaffold to the student’s cognitive development” (p. 165). On the same topic, Roth and Welzel (2001) noted that “gestures provide a medium on which the development of scientific discourse can piggyback” and “gestures allow students to construct complex explanations in the absence of scientific language” (p. 103).

Both teachers remarked about classroom conversations (student discourse) and how important it was for all students to be involved in the inquiry lesson. Both teachers mentioned the students’ discourse and they also described non-verbal student interactions as well (e.g., ‘pointing’). The representation device in this instance was either the students’ computer monitors or the projection screen at the front of the room (and in some instances, the teacher’s Sympodium™), where real-time digital microscope views could also be shared with the whole class. According to Teachers E and A, their students were watching other students' monitors while doing their own inquiry and they were moving around talking and gesturing about what they were seeing. Teacher A observed the students' group dynamics saying they were 'like sponges soaking up new knowledge.'

Roth et al. (1999) studied the interactions of focal artifacts (things to look at and/or study), social configurations, and physical arrangements upon students' science conversations during learning activities. They noted "students' utterances were not so much properties of individuals but evidence of more general assumptions implicit in the common ground shared in the classroom community" (Roth et al., 1999, p. 297). They discussed providing a "forum for conversation" as well as "explicitly organizing learning environments around physical artifacts with the goal of developing a shared discourse" (Roth et al., 1999, p. 297). They found that the artifacts "provide anchors or bridges" (Roth et al., 1999, p. 298) across groups or between individuals, who might have different backgrounds and levels of understanding in the classroom community. In earlier work, Roth (1996b) noted how tool-related practice among principle actors in the classroom community stimulated discourse and the incidence of peer teaching among students.

Both teachers remarked many times on the focal artifacts and the social community of the inquiry classroom, and on student discourse in sharing ideas and discoveries during the lessons. For example, the focal artifact used by Teacher E in some inquiry lessons, namely U.S. currency, became the center of discourse as students thought through such matters as 'why thirteen of so many things,' 'why are most dollar bills from a federal bank nearby,' and 'why would currency designers go to so much trouble to foil counterfeiters.' Teacher A noted that students 'became investigators' when looking at flowers and shells and were always 'talking and pointing' as they examined art objects during art inquiry. Both teachers also mentioned principle actors and peer teaching (students instructing other students) as direct effects of the introduction of digital microscopy into their inquiry activities.

Another related aspect of student interactions with focal artifacts, Jones et al. (2003) brought out the importance of the concept of *haptic perception* among student microscope users. Haptic perception involved perception via touch as well as sight (magnified in this instance) and was important in how students learn about the physical properties of objects beyond their everyday perceptions. For example, Teacher A commented on how students would turn over objects in their hands as they examined them and how the study of texture was 'tactile as well as visual.' The haptic perception of students was obvious to both teachers and they remarked on the students desire to touch objects as they observed them using digital microscopy. Teacher A also mentioned the connection between this and the 'shapes and textures' of art objects and materials.

Teacher Change

Richardson (1990; 1991) found that teacher change generally fell into two main types: teacher learning and program implementation. Regarding these two main types, Richardson's main thesis was that individual teacher's decision to change lay mainly with "an individual's beliefs, attitudes, goals, and knowledge" and "cues from the organizational environment," respectively (Richardson, 1990, p. 11). Richardson also noted that how teachers think and what they believed was important in change, as was the teacher as a person. In explaining change, Richardson (1990, p. 11) found that previous work indicated three factors, namely (1) practicality ("does it allow for classroom contingencies?"), situational ("does it fit my classroom situation?"), and cost, were important to most teachers when they considered change. Motivation was an important factor in teacher change, as reported by Frase and Conley (1994), and this motivation might arise from the desire of a teacher to do something more effective for the students and the curriculum or other external factors.

Both teachers in this study were volunteer participants in the original grant project that introduced the digital microscopes into the elementary classrooms. Both teachers were open to working with the digital microscopes, and they expressed hope at the outset that the digital microscopes would provide improved learning opportunities for their students. Over time, both teachers expressed confidence in using the digital microscope because of its characteristics ('sturdiness' and 'child-friendly' design) and their increased ability and the students' increasing abilities in using the digital microscope. Both teachers recognized that the digital microscope transformed their inquiry lessons and increased its use to the extent that they could in order to gain learning benefits for their students. Further, both teachers noted that they learned about microscopy and computer technology from working with the digital microscope and learned about inquiry methods and their students as well. Teacher A commented that the digital microscope 'showed me things I could not see.'

Student Conceptions

About scientists and science. Carlson (2001) found that most young students think of scientists as older, bearded, Caucasian men who spend time in laboratories, wear white coats, and are surrounded by symbols of knowledge such as computers, clipboards, and books. Schoon (1992) found that children's stereotypical misconceptions occurred across racial groups, economic status groups, educational levels, and between genders. Kusnick (2002) noted these preconceptions could be formed by culture, religion, family, personality, and psychology. Both teachers remarked on how students expressed that they could understand science and scientists better after using the digital microscope and that they 'felt more like scientists.' Students expressed this sentiment to the teachers, even though some students were doing art lessons and social studies lessons, not strictly scientific lessons. Teacher E, whose enrichment class included science activities, remarked on the students' general disinterest in traditional science and science textbooks, but noted how students responded when they participated in a scientific activity. In particular, the science activity lessons with digital microscopy were effective in encouraging participation by all students and interested all students, according to Teacher E. Teacher A spoke about students working as artists but acting like scientists. Teacher A voiced one students' comment when viewing the art lesson's flowers – 'oh, cool that is the stamen.' About student conceptions about how to depict scientists, Teacher A remarked about the students – "I think they will draw a microscope after this.'

About the natural world. Chi et al. (1994) broke down student conceptions into three ontological categories (i.e., matter, process, and mental state) and noted that it was critical that students identify what category or categories they were dealing with before it was possible to effectively modify their conceptions. Nakhleh and Samarapungavan (1999) studied young children and their beliefs about matter, and identified a range of beliefs from macrocontinuous (there are no smaller, invisible parts) to microcontinuous (all matter is made up of much smaller parts). They found that most students have beliefs about matter that fell somewhere between the two beliefs just mentioned, which suggested that the students had no experience with looking closely at objects (e.g., under magnification). Jones et al. (2003) studied what children might think about the world that was too small to be seen and found that there were significant changes in the perceptions of children about very small scale objects after the children were exposed to views of common objects using an electronic microscope.

Both teachers remarked about the fascination expressed by their elementary students as they saw common objects and living things up close for the first time. Both teacher related students' comments such as 'wow' and 'hey, come look at this!' as they excitedly examined items in the enrichment and art lessons. Both teachers expressed the view that they and their students learned that even with small things, 'there is more to it that you do not see.' Teacher A noted 'it could have been coins, or a grain of sand; it could have been anything; it was the whole process of discovery' that there was so much fine detail to see.

Both teachers expressed that some students did not at first understand the difference between the object and the digital image of the object and some thought that the digital microscope made the object larger, not the image. Teacher E explained at one point, 'the object doesn't change, you are just getting closer to it.' Working with the digital microscope was important in changing student perceptions of this phenomenon.

Roth and McGinn (1998) and Roth (2003) described a natural connection between a child's approach to nature and that of a scientist's. Pearce (1999, p. 3) stated that "every child is a scientist … children think in ways that scientists think, say things that scientists say, and do things that scientists do … what pure science it is when a child touches and feels, tastes and smells, examines and manipulates … children are driven to fully examine all they can in their surroundings.” And, Liem (1987) noted that children were naturally excited about scientific discovery and drew also from a teacher’s excitement about scientific discovery.

Both teachers remarked on the digital microscope lessons having an effect of making students ‘feel more like scientists.’ These comments related to science lessons as well as non-science and art lessons. Both teachers described inquiry lessons that were rich with students excitedly sharing discoveries and having discourse about their findings. This mimics the scientific process, for example in a scientific laboratory, where a group of individuals were trying to understand new and interesting information. Teacher E remarked that inquiry with the digital microscope showed students ‘how some scientists out there work for years to discover something.’ Teacher A commented that ‘students associate the microscope with science’ and yet ‘students express their artistic feelings when looking at an object.’

About art and science. Gehlbach (1990) described two basic types of art in the educational context: expression art (i.e., the work of artists) and communication art (i.e., art that served a purpose such as replacing or enhancing written communication). He noted that expression and communication art must be decoded by those who saw it, or stated differently a particular significance would be attached to the art by others. Wright (2000) discussed the similarities between art by artists and art as a consequence of natural science. She noted that artists were concerned simultaneously with the “inner world of ideas and vision and [at the same time] a practical world of materials and technique”

(Wright, 2000, p. 284), whereas natural scientists, experienced this same duality. Natural scientists must deal with the material qualities of things in nature while dealing with their visions of the hidden qualities of natural things and their place in nature. Further, some authors had presented artistic microscopic views of natural world and the world of tiny crystals (Dabdoub, 2003; Davidson & Lotus, 1993; Rotner & Olivo, 1997). About this sort of art, Pestrong (1994) remarked that when studied closely the artistic qualities of natural materials may help “attract and hold the interest of those students who might be disinterested in science or the arts” (Pestrong, 1994, p. 249). Smith and the Drawing Study Group (1998) likened scientific inquiry to artistic expression, as the ancient Greeks did.

Both teachers remarked about the artistic nature of digital images and videos made using digital microscopy. For Teacher E, the digital images and videos of the students were intended to be more communication-type art, but the teacher found that many of the digital images and videos were artistic in and of themselves (i.e., expression art). Teacher A intended most of the digital images and videos of the students to be expression-type art, but found that there was a communication art aspect as well. Both teachers expected for the digital images and videos to be interpreted (decoded) by their respective students, but for different reasons, consistent with the nature of the inquiry lesson. Both teachers, again for different reasons, found that students looked at the digital images and videos made by the digital microscope and saw the ‘hidden meaning’ necessary for the lessons’ objectives while at the same time being attracted to the artistic aspects of the digital images and videos regardless of the nature of the lessons. Both teachers remarked about the ‘science-art connection’ in their lessons. Teacher A found that students saw connections between ‘art lessons and the discipline of science’ and that art and science ‘flowed back and forth’ in the lessons.

Georgia O’Keeffe (1887–1986) was an artist whose name was closely associated with a strong bond with nature. O’Keeffe was best known for her paintings of magnified flowers and New Mexico landscapes (Benke, 2000; Robinson, 1989). Benke (2000) noted that the artist Georgia O’Keeffe wanted to make small things like flowers larger so that people would notice them in her paintings and would begin to think about them and described Georgia O’Keeffe’s works as complete, large-size views of flowers and natural objects. Many art teachers used art lessons inspired by Georgia O’Keeffe in classrooms today, including Teacher A.

Teacher A had a long-standing interest in the work of Georgia O’Keeffe, who Teacher A commented had ‘microscope-kind-of-eyes.’ The teacher had previously taught lessons on the O’Keeffe art style, but had been seeking a different way to attain artistic views similar to O’Keeffe’s. Teacher A noted that the new way was in using digital microscopy. Teacher A remarked how similar the Georgia O’Keeffe style was to the students’ digital images of flowers and shells. Teacher A was ‘amazed at the students’ compositions.’ Teacher A noted that like O’Keeffe’s work, the students using the digital microscope could ‘zoom in on certain parts’ of the flower or shell and that the digital microscope’s view ‘blocked out things around’ the area as an O’Keeffe painting might do. Teacher A commented that students could ‘get lost in their images,’ which was a vision that Georgia O’Keeffe had for her art work and the viewing public.

Digital Microscopy

Some time around the year 2000, digital microscopy was introduced in research and educational applications. Davidson (1998–2004, chap. 3, p. 1) described this new technology saying: “Digitization of a video or electronic image captured through an optical microscope results in a dramatic increase in the ability to enhance features, extract information, or modify the image. When compared to the traditional mechanism of image capture, photomicrography on film, digital imaging and post-acquisition processing enables a reversible, essentially noise-free modification of the image as an ordered matrix of integers rather than a series of analog variations in color and intensity.” Initially, the technology was used for digital capture, but it quickly evolved to digital video as well (Davidson, 1998-2004). As Davidson (1998-2004) pointed out, digital microscopy grew out of the sea change in photographic imaging that came with the development and marketing of relatively inexpensive digital cameras and associated software for image processing and printing (Keith et al., 2003).

Both teachers mentioned the ‘child-friendly’ aspects of the digital microscope, its sturdiness and low cost, and its versatility, flexibility, and practicality. Teacher A remarked that the digital microscope ‘just invites the child to come and explore’ and that it ‘shows them things with a different set of eyes.’ Both teachers mentioned the restrictions that the standard light microscope had versus the digital microscope and the fact that the digital microscope could instantly capture an image. Both teachers noted that students worked with the digital microscope in its stand and in the hand-held mode as needed. Both teachers noted that students used the graphics capability of the digital microscope software and this enhanced the lessons. Teacher E encouraged students to label their photographs using the graphics software, whereas Teacher A wanted students to explore with the graphics capabilities. Teacher A commented at one point that students could use the software to ‘flip colors’ and make ‘an Andy Warhol-kind of image’ with the software. Teacher A noted that the students ‘discovered textures’ and ‘experienced art’ using digital microscopy and the teacher mentioned the ‘unusual twist’ that the digital microscope brought to art lessons and that it would help with painting and drawing lessons as well.

Conclusions and Implications

Conclusions

The results and findings of this study revealed that the introduction of the digital microscope into elementary classrooms had many similar effects during enrichment and art lessons. Both the enrichment teacher (Teacher E) and the art teacher (Teacher A) experienced the following:

1. For both teachers, the introduction of digital microscopy started as a scientist-teacher collaboration evolved into a teacher partnership with their respective students. As the teachers’ routine lessons evolved into inquiry lessons using digital microscopy, the teacher-students partnership evolved too.

2. Both teachers practiced *authentic inquiry*, a term used in this study as a generic version of the more common term authentic science. Authentic inquiry emerged during their respective inquiry lessons for enrichment (science and non-science) and art classes.

3. Both teachers began by directing their respective enrichment and art lessons in a traditional way (i.e., the teacher leading the lessons), but the lessons became more student-driven, and went in unexpected directions and yielded unexpected results. There were many emergent properties of the respective lessons.

4. Both teachers noted that students expressed a strong sense of ownership of their digital microscopes, digital images and videos, and discoveries. And, both teachers found that the students wanted to share those things with classmates and at home.

5. Both teachers felt that the digital microscope helped them find new ways to meet educational standards and that the lessons with digital microscopy had strong interdisciplinary potential. Both teachers noted that students recognized the interdisciplinary nature of their lessons. And, both teachers wanted to share digital microscopy with other teachers as well and both spoke about wanting to make digital microscopy web-pages.

6. At the students' request, both teachers gave students additional time with digital microscope lessons and time to think about the lessons. Both teachers in effect described the processes of metacognition and of scaffolding from preexisting understandings as important elements in their respective students' work with digital microscopy. Both teachers described the effect of discrepant events on student learning, which stimulated student inquiry during digital microscopy lessons.

7. Both teachers described students 'learning by thinking about what they have done' (Piagetian cognition) as well as 'learning by experiencing lessons' (Vygotsky-type cognition) during inquiry-based, digital microscope lessons. Both

teachers reported learning about an object by touching as well as viewing it (haptic perception) among their respective students.

8. Both teachers reported the same sort of student interactions during digital microscope lessons, such as: wanting to work as a group (not in assigned pairs); wanting to look at what they wanted to see; wanting more time for lessons and to think about the lessons; engaging in discourse (including utterances, gestures, and body language) about their findings; and wanting to see what others were finding all the time and all at the same time. These interactions characterized both enrichment (science and non-science) lessons as well as art lessons.

9. Both teachers voluntarily changed their lessons to accommodate the use of the digital microscope and continued to use the digital microscope in their lessons over the period of the study, citing initially practicality and utility issues, but later saying that the efficacy of the digital microscope was a factor (i.e., student interest and enthusiasm, etc.).

10. Both teachers remarked that students told them that they felt more like scientists, felt more scientific, and understood science and scientists more during and after using the digital microscope. This feeling was expressed in non-science (art and enrichment) lessons as well as science lessons.

11. Both teachers noted that students' understanding of the finer structure of natural and man-made objects was improved by using digital microscopy and that students connected very small (i.e., previously unseen things like parts of a flower and a bee's stinger) to their functions in nature.

12. Both teachers noted that students found both artistic and scientific content in their lessons, regardless of topic. The enrichment teacher (Teacher E) asked the students to use the digital microscope to document scientific things like structures on an insect's body, crystals forming in a liquid, growing plants, and scratches on metallic coins. Also, Teacher E asked students to look at fine details on U.S. and other currency. In the process of doing this, students found artistic features that evoked feelings, which they expressed. Teacher A asked the students to look at the artistic aspects of natural objects (flowers and shells) and in the process, they noted scientific details.

13. Both teachers planned some specific lessons that they really wanted to do using digital microscopy. In some social studies lessons, Teacher E asked students to look at U.S. currency and currency from other countries and think about what they were seeing. In some lessons, Teacher A specifically wanted students to study the style of the artist Georgia O'Keeffe using digital microscope and think about what they were feeling. Both teachers reported that the inquiry lessons greatly exceeded their expectations in using digital microscopy and represented some of the most creative work their students had ever done.

The enrichment teacher (Teacher E) and the art teacher (Teacher A) experiences with digital microscopy were different in several ways.

1. Teacher A remarked more about the effects of the initial scientist-teacher partnership than did Teacher E.

2. Teacher E tended to focus more on the computer-related aspects of the digital microscope lessons than did Teacher A.

3. Teacher E applied digital microscopy over a wider range of activities than did Teacher A.

Implications

This study showed that across the subject areas in enrichment and art, introduction of the digital microscope into elementary classrooms had many positive effects upon both the enrichment teacher and the art teacher – and their respective lessons. The introduction of this new tool stimulated both of the teachers to conduct some of their respective lessons differently from the past (and to change those lessons as the students adapted to inquiry). The digital microscope and the way the teacher employed it caused their students to respond differently to those lessons than in the past. As a result, these new enrichment and art lessons achieved new kinds of results. In particular, this new tool provided not only a new way of seeing (three-step, microscopic magnification) but also was a new way for all to see (the computer monitors connected to individual digital microscopes and the big screen at the front of the room that was connected to the digital microscopes). Each time, these stimulated student-teacher interactions and student discourse around graphic displays and digital images. The students behaved more like scientists in a laboratory and artists in an art studio than students in a typical classroom. Both teachers used digital microscopy over the time period of this study, and their remarks suggested that they would continue to do so.

The general implications of this study were that any time new tools that promoted authentic inquiry were introduced in the elementary classroom and students were given freedom to use the tools, a change in the learning community would be the result. A specific implication of this study was that the inexpensive and sturdy digital microscope technology was a new tool that could transform a variety of subject-area classrooms by virtue of its graphics and display capabilities, including instantaneous digital image capture and related digital video functions.

Although the researcher is still learning about the effects of introducing digital microscopy into elementary classrooms, the experience with this study suggested that initial external input (like the scientist-teacher collaboration grant project that initiated this study) helped teachers using the new technology. While it was important for this scientist-teacher connection to be continued, once teachers like Teacher E and Teacher A allowed students to begin lessons with digital microscopes, the transforming nature of the new tool and the students' natural curiosity helped maintain the effectiveness of the lessons. Students experience what the researcher calls *digital visualization*, a stepping stone to understanding. If teachers like those in this study allowed students time to explore with the digital microscope, the natural scientist and artist in them would emerge. This in turn encouraged the teacher using digital microscopes to continue to do so and to look for new ways to include this new technology in lessons.

As a further extension of this study, it would be interesting to observe the introduction of digital microscopy in other classrooms and at other schools. In order to accomplish this, the researcher would recommend that such a project have the following aspects: a university science-department collaboration; volunteer teachers who would mentor other teachers; a support system for the exchange of ideas (through the Internet, colloquia, etc.); involvement of all stakeholders; students being allowed freedom to explore with the technology; and sufficient time and resources devoted to the success of this new technology.

These are some future research questions to ask:

1. Will these teachers and other teachers continue to use digital microscopy in the future?

2. Will collaboration continue on a larger scale and if so how might that happen?

3. If the resources were available and digital microscopy could be introduced into more classrooms in a wider area, what would the effects be?

4. Will future students in elementary school be more technically savvy so that computer-based equipment like the digital microscope might be less interesting to them?

5. What long-term effect did this digital microscope experience have on the students at this elementary school? As they go through middle and high school and into college or careers, will they view science and technology differently?

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APPENDICES

APPENDIX A

TABLES, FIGURES, and COMPACT DISC

The outline that follows shows the organization of this appendix. The reference codes in this appendix, e.g., E-NB1-1, mean Teacher E (or A) – Notebook number (1-3), and tab number (1-15). For digital files, the reference codes are, e.g., E-DFF-2004-05-01, which mean Teacher E (or A), digital folder or file (DFF) created on year (2004), month (05) and day (01). Appendix D contains a list of all reference codes and sources.

I. Tables

Tables A1 and A2

II. Figures

Figures A1-A11

III. Compact Disc

Files E-CD and A-CD.

I. Tables

Table A1

Parallel Arrangement of Steps in the Scientific Method (from Lawless & Rock, 1998)

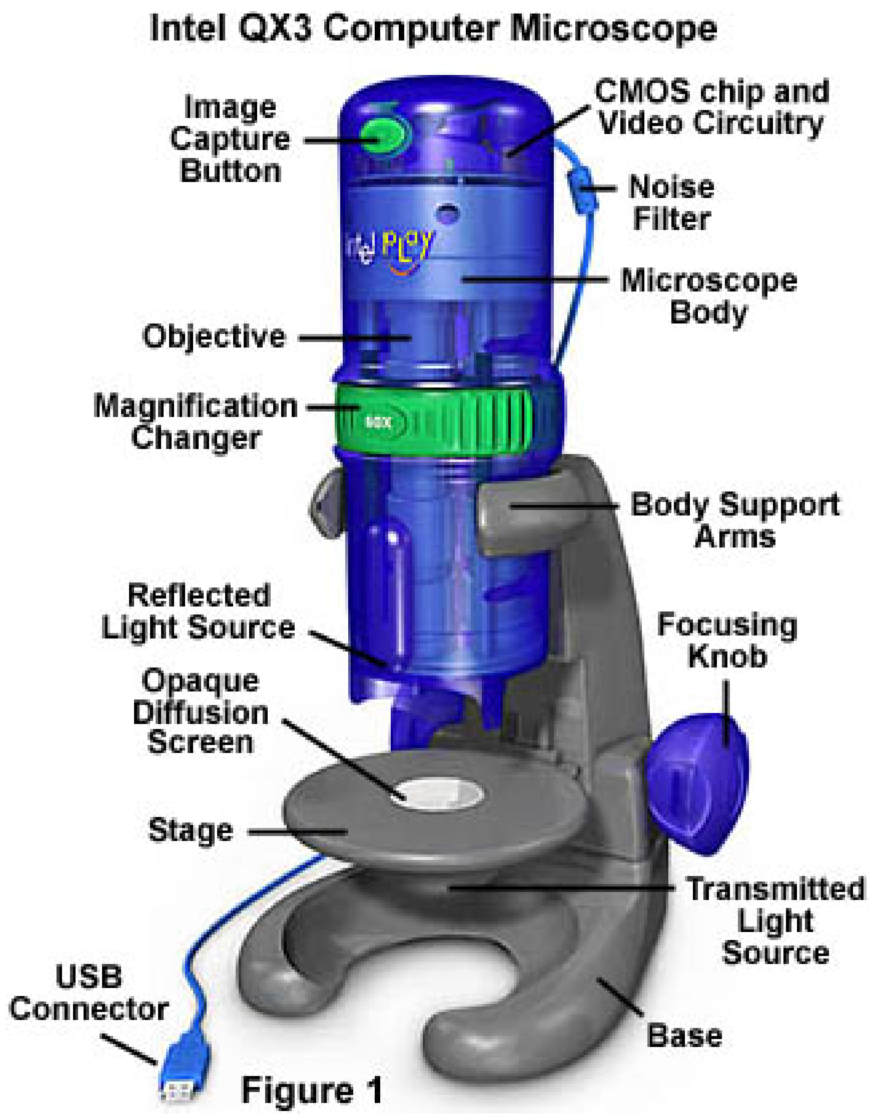
Steps in the scientific method	*Educational objectives of the science classroom*
Observation	Awareness of nature
Scientific hypothesis	Inquiry and questioning
Experimental design	Conceptualization
Instrument selection	Decision making
Data acquisition	Recording and note keeping
Data quality and analysis	Comparison, contrast, and judgment
Analysis of results	Evaluation and interpretation
Conclusions	Creative thinking and synthesis
Report on findings	Self expression and communication

Table A2

Steps in Data Collection and Analysis

Time line	*Steps in Data Collection*	*Steps in Data Analysis*
Early 2004	Informed Consent	
Early 2004	Teacher Surveys	Formulate Interviews
Spring 2004	Preliminary Interview	Review and Reduce Data
Spring 2004	Interview after First Lesson	Review and Reduce Data
Early summer 2004	Post-interview	Review and Reduce Data
Summer 2004	Participant Workshop	
2004-2006	Classroom Observation	Review Early Conclusions; Gather Data on Participants
Early 2006	Interview After Lessons	Review and Reduce Data
Early summer 2006	Second Post-Interview	Review and Reduce Data

II. Figures



Source: Davidson (1995-2004).

Figure A1. Digital Blue™ QX3™ Computer Microscope with Parts Labeled

Figure A2. Digital Blue™ QX3™ Microscope Connected to a Laptop Computer

Source: Researcher digital files E-DFF-2004-04-19 and E-DFF-2004-05-07.

Figure A3. Crystal Growing Lesson, Teacher E’s Classroom (2004). Inset: Student’s Sketch of Salt Crystals.

Source: Researcher digital file E-DFF-2005-12-08.

Figure A4. Teacher E’s Lessons in the School’s Computer Laboratory (2005); Currency (top and lower left) and Coins (lower right).

Source: Researcher digital files A-DFF-2004-05-4, A-DFF-2004-05-05, and A-DFF-2004-05-12.

Figure A5. Teacher A’s Georgia O’Keeffe Art Lesson in School Computer Laboratory (2004). Lower Parts: Flowers on Computer Screens

Source: Researcher digital files A-DFF-2004-05-13b.

Figure A6. Teacher A's Examples of Students' Digital Photographs of Flowers and Shells from Art Lessons on Georgia O'Keeffe (2004)

Source: Researcher digital file A-DFF-2004-05-13a.

Figure A7. Art Lessons Using Their Own Digital Microscope Photographs, Teacher A's Classroom (2004)

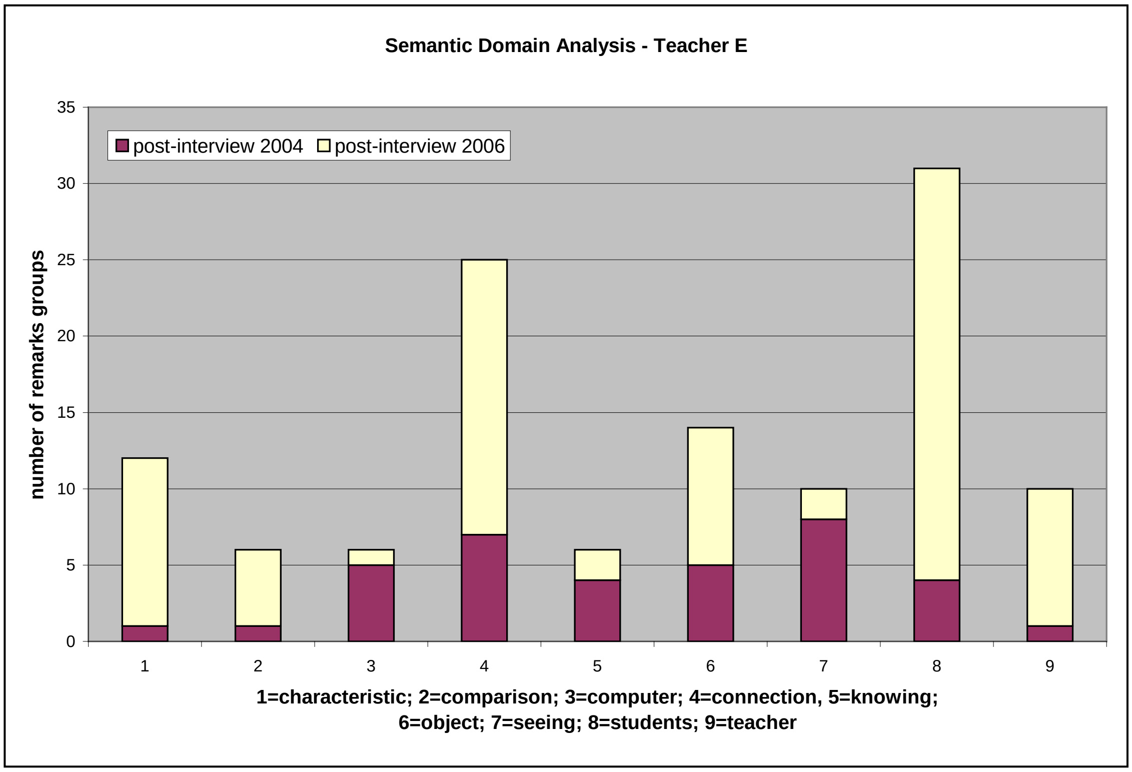


Figure A8. Histogram Showing the Relative Number of Remark Groups for Teacher E based on the Post-Interviews 2004 and 2006.

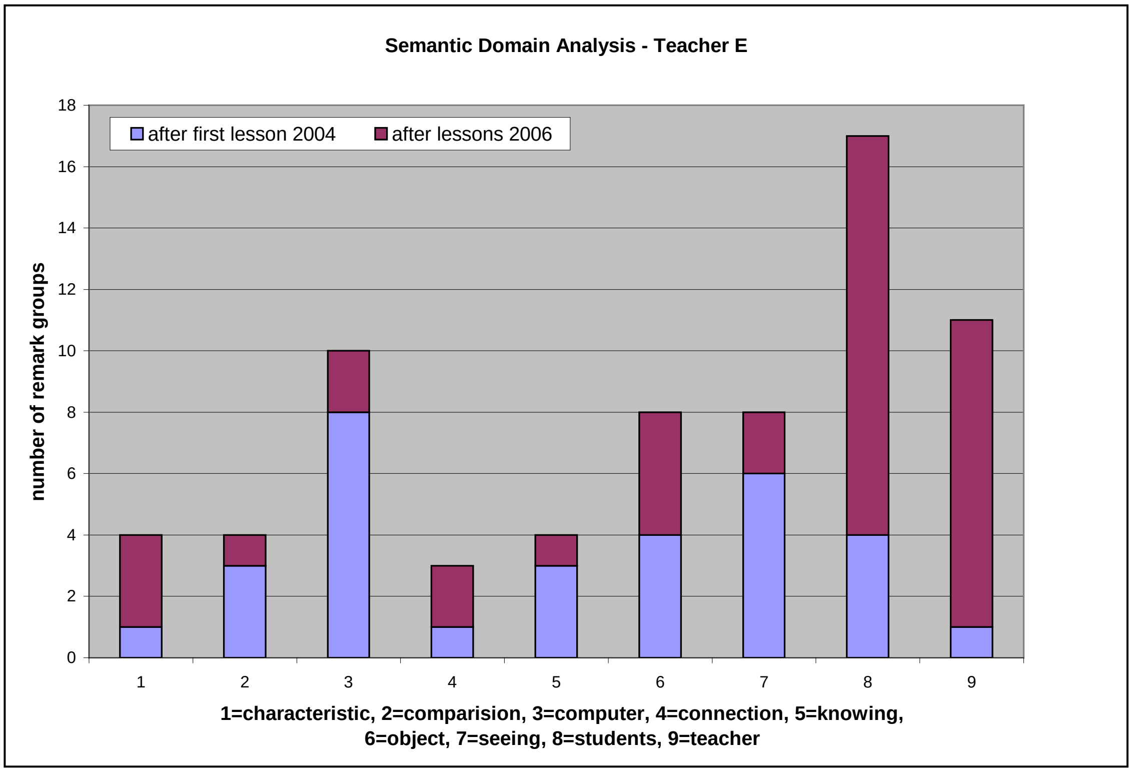


Figure A9. Histogram showing the Relative Number of Remark Groups for Teacher E based on the Interview after First Lesson 2004 and the Interview after Lesson 2006.

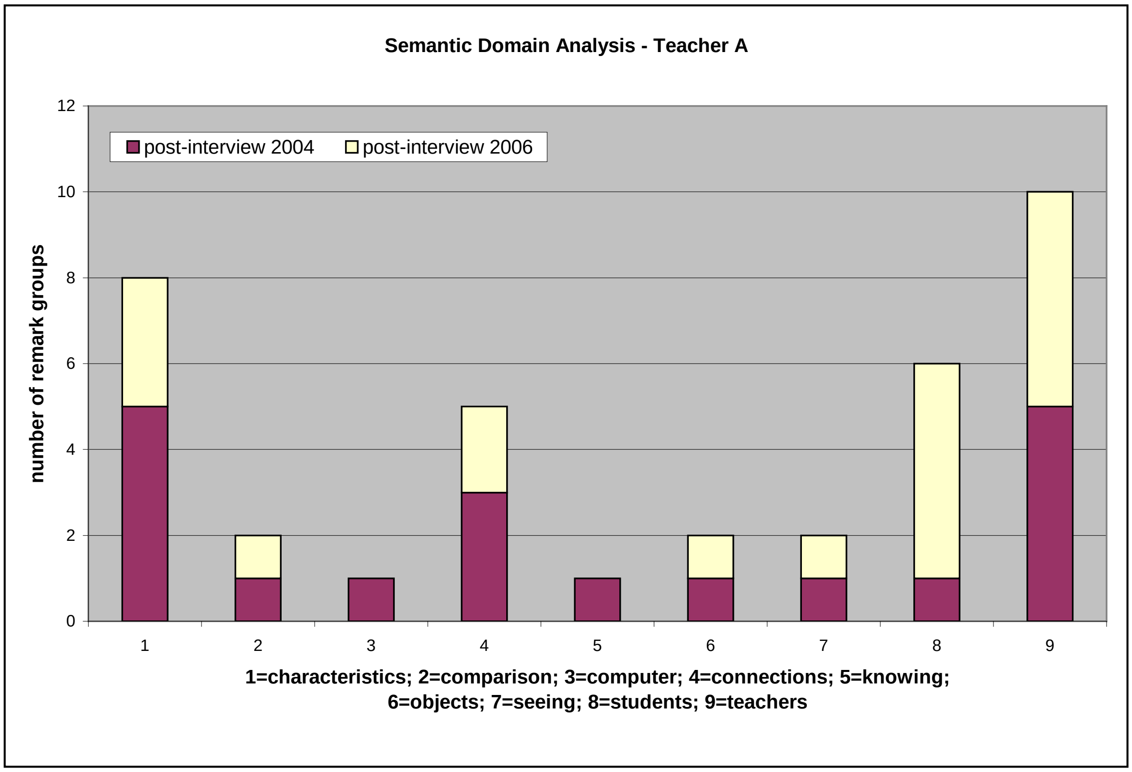


Figure A10. Histogram showing the Relative Number of Remark Groups for Teacher A based on the Post-Interviews 2004 and 2006.

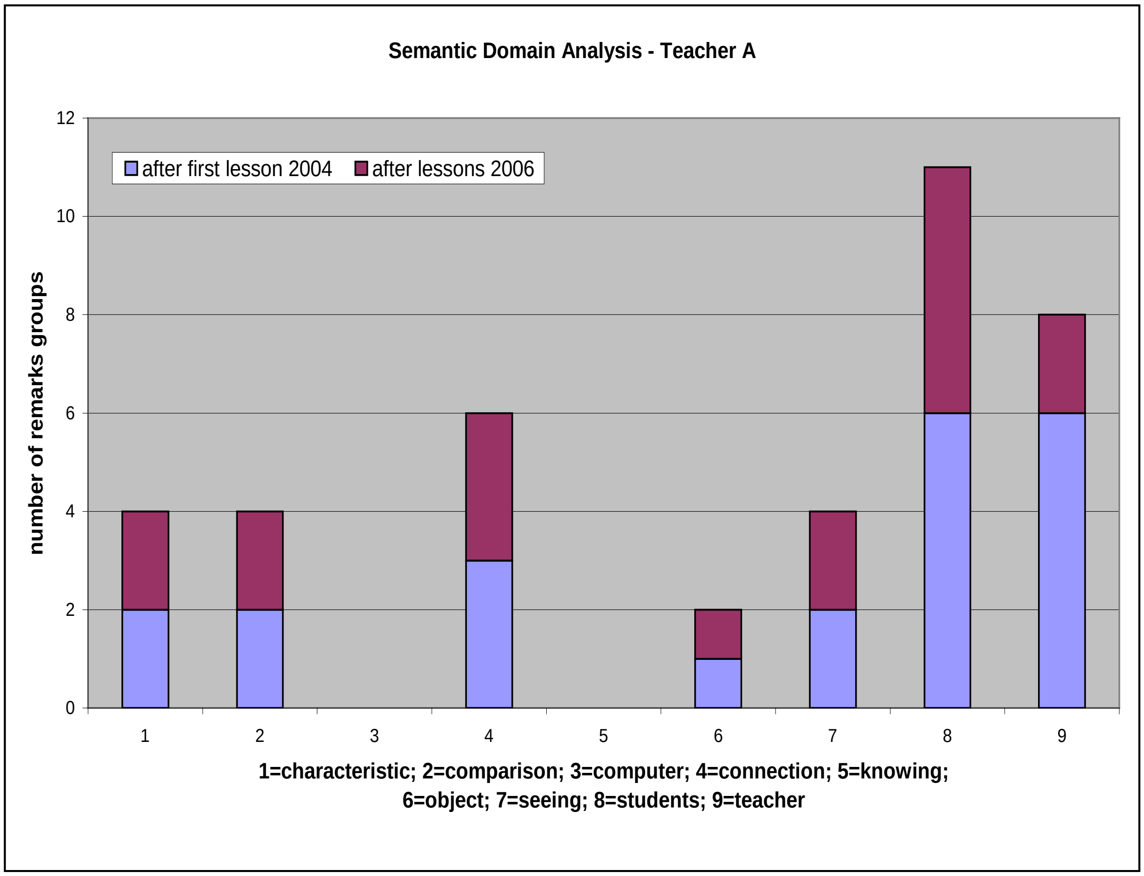


Figure A11. Histogram showing the Relative Number of Remark Groups for Teacher A based on the Interview After First Lesson 2004 and the Interview After Lessons 2006.

III. Compact Disc

File E-CD is a PowerPoint presentation with 65 slides showing images made by the researcher during classroom observations and lessons in the computer laboratory with Teacher E. These slides show the teacher's classroom, the school's computer laboratory where some student lessons were taught, lessons using digital microscopy (crystal growing, currency, and coins), and examples of student sketches from a crystal-growing lesson in 2004.

File A-CD is a PowerPoint presentation with 46 slides showing images made by the researcher during classroom observations and lessons in the computer laboratory with Teacher A. These slides show the teacher's classroom, the school's computer laboratory where some student lessons were taught, lessons using digital microscopy (lessons on Georgia O'Keeffe-style art, including digital photography, drawing, and painting), and examples of student digital microscope images from a lesson in 2004.

This compact disc is in an envelope attached to the back cover of this volume.

APPENDIX B

INFORMED CONSENT DOCUMENT AND INTERVIEW QUESTIONS

The outline that follows shows the organization of this appendix. The reference codes in this appendix, e.g., R-NB1-1, mean researcher (R) – Notebook number (1-3), and tab number (1-15). Appendix D contains a list of all reference codes and sources.

I. Informed Consent

Approved informed-consent document used in this study (2004) (Source: R-NB1-1 and 2)

II. Prepared Questions

A. Preliminary interview for participating teacher (2004)

B. Interview after first lesson for participating teacher (2004)

C. Post-interview for participating teacher (2004)

D. Interview after lessons for participating teacher (2006)

E. Post-interview for participating teacher (2006)

Auburn University

Auburn, Alabama 36849-5212

Curriculum and Teaching Telephone (334) 844-44343
College of Education Fax (334) 844-6789
5040 Haley Center

INFORMED CONSENT DOCUMENT

for the study titled

How does the introduction of the digital microscope into the K-12 science curriculum affect science teachers' approaches to science education?

You are invited to participate in a research study involving you as a teacher and a microscopist-mineralogist. This study is being conducted by Lucille Petruny, a doctoral candidate in the Department of Curriculum and Teaching at Auburn University under the supervision of Dr. Elizabeth Senger, Associate Professor of Curriculum and Teaching. We hope to learn more about the potential for the digital microscope to positively affect science education. You were selected as a possible participant because of your past involvement with progressive science education and your previous expressed interest in this project.

If you decide to participate, we will be working with you on implementing digital microscopy in your classroom between now and January, 2005.

The only risk that I foresee is the social risk of doing something different from the other teachers in your grade level.

It is anticipated that you will gain satisfaction in sharing the outcome of your work with an interested researcher. You may also gain insight into new technology and how to use the digital microscope in your future classes. We cannot promise you that you will receive any or all of the benefits described.

Any information obtained in connection with this study and that can be identified with you will remain confidential. Only the researcher, her advisor, the university faculty specialist involved will have access to your data. At the end of the study, data will be destroyed or returned to you. Information collected through your participation may be used to fulfill Lucille Petruny's dissertation requirement, published in a professional journal, and/or presented at a professional meeting. If so, none of your identifiable information will be included. You may withdraw from participation at any time during this study. You may also withdraw any data that you wish not to be included in this study.

____
Participant's Initials
(required for all non-signature pages)

Your decision whether or not to participate will not jeopardize your future relations with Auburn University, the Department of Curriculum and Teaching, your school or school system, or the researcher in any manner.

If you have any questions we invite you to ask them now. If you have questions later, Lucille Petruny (334 502-8014; petrulb @ auburn.edu), or her advisor, Dr. Betty Senger (334 844-6888; sengees @ auburn.edu) will be happy to answer them. You will be provided a copy of this form to keep.

For more information regarding your rights as a research participant you may contact the Office of Human Subjects Research by phone or e-mail. The people to contact there are Executive Director E.N. "Chip" Burson (334) 844-5966 (bursoen @ auburn.edu) or IRB Chair Dr. Peter Grandjean at (334) 844-1462 (grandpw @ auburn.edu).

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

______________________________	______________________________
Participant's signature Date	Investigator's signature Date
______________________________	______________________________
Print Name	Print Name
______________________________	______________________________
Parent's or Guardian Signature Date (if appropriate)	Co-investigator's signature Date (if appropriate)
______________________________	______________________________
Print Name	Print Name

II. Prepared Questions

A. Preliminary interview for participating teachers (2004)

1. Do you think students like to look at magnified object and why?
2. Do you think a microscope is a good tool for inquiry for student learning?
3. Do you use microscopes in your class or have you ever used them?
4. Do you think using microscopes in class will help you meet the science standards for the state or the school?
5. What subject areas do you think may benefit by utilizing this kind of microscope?
6. Do you feel comfortable using microscopes and computers in class and explain a bit of your background?
7. Do you think students gain insight into the nature of science by using the microscope as a part of a science lesson – in other words – do they understand what a microscope is used for in science?
8. How do you think that scientists and teachers can gain insight into how students develop an interest or enthusiasm for science by using this microscope?
9. What activities do you think would benefit by using a microscope in the class that maybe has not happened before?
10. Can you describe a successful activity that you have done using just the regular, light microscope not the digital?
11. Can you describe an activity that you would like to try using this computer microscope technology?

12. Can you describe any problems or concerns that you have had using a microscope in class that is very typical of using a microscope in a classroom?
13. Describe how this microscope can help address these concerns.
14. Do you see any interdisciplinary connections, for example with math or chemistry, that you can use from this microscopy lesson?
15. What kinds of activities would you recommend for your students using the microscope?
16. What is the first thing that you did with the microscope and what you thought the first thing students would do with the microscope?
17. What do you think the students would like about the microscope?
18. What are your expectations then for utilizing the microscope with your class? What are you looking for and where do you see it going?
19. What benefit do you think the students will gain by using the microscope?
20. What do you think that microscopy can teach students about the broader world of science?
21. What are your expectations by being involved with this collaborative project between other teachers and university scientists?
22. What questions do students ask while investigating activities using this digital microscope? What do you think some questions are going to be?
23. What images do you think that your students possess of scientists that you have noticed?

24. What kinds of opportunities to you expect might arise from use of the digital microscope?

25. Do you have anything else that you would like to say about this project that we haven't covered today?

B. Interview after first lesson for participating teachers (2004)

1. How did your preparation help in your first lesson?

2. What did you learn about digital microscopy and overall microscopy that helped you when working with the students in this introductory lesson?

3. What did you observe about what seemed to interest the students in this first lesson?

4. What would you have done differently or keep the same about an introductory lesson?

5. Do you have any concerns about the equipment, class set up, or management for the first lessons in general?

6. Do you see the computer lab as helpful?

7. What do you think was an important outcome of implementing this digital microscopy into a classroom? What is an important outcome so far?

8. How does using digital microscopy help in affecting change in your science curriculum so far?

9. How did using this microscope help you get an insight into how students learn?

10. What did you notice about a conversation or collaboration during the introduction to the digital microscope?

11. Did you notice any changes to student’s interests or behaviors, gender differences, or grouping variations?
12. How is your interest in implementing this digital microscopy affecting you personally or professionally so far?
13. What will you do next with your students now that you have had your first lesson?

C. Post-interview for participating teachers (2004)

1. Did you find students liked to look at magnified objects? Why?
2. Did you find that a microscope was a good tool for inquiry for student learning and why?
3. What kind of experiences did you have working with the microscope either in your own education or in your teaching?
4. Do you think using microscopes in class helped or enhanced your ability to meet state standards?
5. What subject areas benefited by utilizing this microscope?
6. Did you feel comfortable using microscopes and computers in class?
7. Did you think students gained insight into the nature of science by using the microscope as a part of a science lesson?
8. What did you discover about how scientists and teachers can gain insight into how students develop an interest or enthusiasm for science by using this microscope?
9. What activities did you think benefited by using a microscope in your classroom?

10. Describe a successful activity that you have done using microscopy but not digital microscopy in the past.
11. Describe an activity you did using digital microscopy.
12. Describe any problems or concerns that you had using a microscope in a lesson.
13. Describe how using the digital microscope helped in addressing these concerns.
14. What kind of interdisciplinary connections did you discover for microscopy lessons?
15. What kinds of activities would you recommend now for your students using the microscope?
16. What did you discover were some of the first things that the student looked at with the digital microscope?
17. What did you find that the students liked about this digital microscope?
18. Thinking back to what your expectations were for utilizing the microscope with your class did you find that your expectations were met? Tell me about them and if they were met or not.
19. What do you think the students gained by using this microscope?
20. What do you think the microscope or microscopy taught the students about the broader world of science like what you just started with that before?
21. Thinking back to your expectations about being involved in this collaborative project (collaboration with the university and the other teachers) did you find that your expectations were met?

P-1. What recommendations do you have for continuing this project in the future? Do you have any recommendations?

P-2. If you were given a wish list, what things would you like to get that would help with the implementation? What do you need for your classroom?

P-3. From your participation in this collaborative project what would you like to learn about microscopy or digital microscopy or the implementation of the digital microscope in the classroom? What is your next goal?

D. Interview after lessons for participating teachers (2006)

1. How did your preparation help in your digital microscopy lessons?
2. What did you learn about microscopy that helped you when working with the students?
3. What did you observe during the lessons on how students see using the digital microscope?
4. What did you observe about what seemed to interest the students in digital microscopy?
5. What did you do differently when doing the microscopy lessons and or keep the same? What did you do differently when doing digital microscopy lessons?
6. Do you have any concerns or recommendations about the equipment, class set up, or management that you could suggest?
7. What do you think were important outcomes of implementing the digital microscopy into your classroom?
8. Did using the digital microscope affect change in your art/enrichment/science curriculum?
9. Did using the digital microscope help you gain an insight into how students learn?
10. Did you observe student collaboration?
11. Did you observe any changes to student interests or behaviors, gender differences, group dynamics?
12. Has implementing the digital microscope into your class affected you personally or professionally?

13. What are your future plans for using digital microscopy in the classroom?

14. Do you have anything else to share about implementing the microscope that we have not talked about that you want to say?

E. Post-interview for participating teachers (2006)

1. Thinking back over the past two years with the digital microscope, did you find that students like to look at magnified objects and why?
2. Did you find that the microscope was a good tool for inquiry for student learning?
3. What has the digital microscope added to your experience in microscopy?
4. How has using digital microscopes in your class help you enhance state standards or meet state standards?
5. What subject areas do you think benefit by using this microscope?
6. Do you feel comfortable now using digital microscopes and computers in class?
7. Do you think students gained insight into the nature of science by using the microscope as part of the art lessons?
8. How do scientists or teachers gain insight into how students develop an interest or enthusiasm for art/enrichment/science by using the digital microscope?
9. What activities benefited by using a digital microscope in the classroom?
10. Describe a successful activity that you have done using microscopy but not digital.
11. Describe one or two memorable activities that you used the digital microscope.
12. Describe any problems or concerns you have had using a standard light microscope in a lesson.
13. How did the digital microscope help address these concerns?
14. What kind of interdisciplinary connections did you discover from the digital microscopy lessons?

15. What kind of activities would you recommend for future students using the microscope? What would you like to try?
16. What were some things that the students enjoyed looking at using the digital microscope?
17. What did you find that the students liked about the digital microscope?
18. Thinking back to what your expectations were for utilizing the microscope with your class, did you find that they were met, and tell about if something happened that you did not expect.
19. What do you think the students gained by using this microscope?
20. What do you think the microscope or microscopy taught the students about the broader world of science?
21. Thinking back to what your expectations were at first being involved with this collaborative project, did you find your expectations were ultimately met? Did some things happen that you did not expect?

    P1. What recommendations do you have for continuing the use of the digital microscope or digital microscopy with your class?

    P2. If you were given a wish list, what would you like to get that would help with implementing digital microscopy in your classroom?

    P3. From your participation in this collaborative project, what would you like to learn about microscopy or digital microscopy, or implementing it more in your classroom?

P4. Do you have any other questions, or ideas, or topics to discuss? Do you have anything else to add about successes?

APPENDIX C

TEACHERS' BACKGROUNDS AND CLASSROOM DESCRIPTIONS

The outline that follows shows the organization of this appendix. The reference codes in this appendix, e.g., E-NB1-1, mean teacher (E or A) – Notebook number (1-4), and tab number (1-15). Appendix D contains a list of all reference codes and sources.

I. Backgrounds of Teachers

A. Background of Teacher E (Source: E-NB1-2 to 7)

B. Background of Teacher A (Source: A-NB1-2 to 7)

II. Classroom Descriptions

A. Classroom of Teacher E (Source: E-NB1-1)

B. Classroom of Teacher A (Source: A-NB1-1)

C. School's Computer Laboratory (Source: E-NB1-1)

I. Backgrounds of Teachers

Table C1 compares the backgrounds of Teacher E and Teacher A. The sources for this table were E-NB1-1 and A-NB1-1.

Table C1

Background Information for Each Teacher Interviewed in this Study (as of January, 2006)

	Teacher E	*Teacher A*
Years of experience	19	19
Major in college	Elementary Education, K-6	Art Education, K-12
Grades taught	1-5	1-5
Occupation and personal interests (order according to teacher participant's responses)	Computers and technology, nature, water sports, family and children	Family and children, art, nature, geology

A. Background of Teacher E

As of January, 2006, Teacher E had nineteen years teaching experience, all at the elementary level (grades 1–-5). The teacher's degree is in Elementary Education (K–6) with an emphasis on computers and technology. This teacher taught only enrichment classes at the elementary school where the teacher was employed. During the school years over which the teacher was observed and interviewed (2003–2004, 2004–2005, and 2005–2006), the teacher taught grades 1–5 and worked with students in grades 1–5 on digital microscopy lessons.

In a typical year (e.g., 2005–2006), the teacher taught students from all grades, both low and high achievers. Some classes were taught with small group “pull-outs,” especially in grades three, four, and five. Over the period of this study, Teacher E taught lessons in the area of general enrichment activities and computer enrichment. Some of the specific topics taught during the period of this study were: Earth science (rocks and minerals); crystal growing; coins and currency; introduction to microscopes; insects (lady bugs and butterflies); and fingerprints.

Teacher E had a special interest in computers and technology and used the digital microscope as a way to teach both microscopy and computer technology. Outside the classroom, the teacher described personal interests as nature, water sports, family, and children.

Teacher E occasionally attended educational technology conferences at the state level. During this study, the teacher also attended the 2005 American Educational Technology Conference (ATEC) meeting and discussed the teacher’s work with the digital microscope with other teachers there.

During observed lessons in 2005–2006, Teacher E worked with enrichment classes on crystal growing, observations on currency and coins, and looking at insects.

B. Background of Teacher A

As of January, 2006, Teacher A had nineteen years teaching experience, all at the elementary level (grades 1–5). The teacher's degree is in Art Education (K-12) and she taught only art at the elementary school where the teacher worked. During the school years over which the teacher was observed and interviewed (2003–2004, 2004–2005, and 2005–2006), the teacher taught grades 1–5 and worked with students in grades 2–5 on digital microscopy lessons.

In a typical year (e.g., 2005–2006), the teacher would teach six first-grade classes, six second-grade classes, five third-grade classes, four fourth-grade classes, and three fifth-grade classes.

Over the period of this study, Teacher A taught lessons on elements of art, principles of design, and great artists like Georgia O'Keeffe. All grades were taught as full-class assignments; there were no small group classes.

Teacher A has a special interest in Georgia O'Keeffe and used the digital microscope on some lessons related to this famous artist. Outside the classroom, teacher A listed personal interests as family and children, art, nature, and geology.

Teacher A attended annual art conferences at the state level. During this study, Teacher A also attended the 2004 National Science Teachers' Association (NSTA) meeting and made a presentation at that meeting for other teachers on the teacher's success with teaching Georgia O'Keeffe lessons (including use of the digital microscope).

During some observed lessons in May, 2005, Teacher A discussed Georgia O'Keeffe before starting the students on a study of O'Keeffe's artistic style. Teacher A explained to the students that the lesson was based on the life work of Georgia O'Keeffe, a famous artist who painted flowers, shells, and bones from the desert in oils, watercolors, and inks. Teacher A explained that this artist is known for her very large drawings of these three things; some of her paintings are the size of an entire wall. After showing a picture of the artist, Teacher A showed the students specific examples of the works of O'Keeffe. The lesson involved students connecting with O'Keeffe's style, point of view, and her message in art. The students were shown how to use the digital microscope to see intricate parts of the flowers and shells that they would choose from to do their art. Teacher A explained to the students that the point of O'Keeffe's art style was to make people stop and look at the details of nature whether they wanted to or not. The students were very creative and successful at this activity.

Teacher A continued working with Georgia O'Keeffe lessons using digital microscopy during the school year 2005–2006 as well.

II. Classroom Descriptions

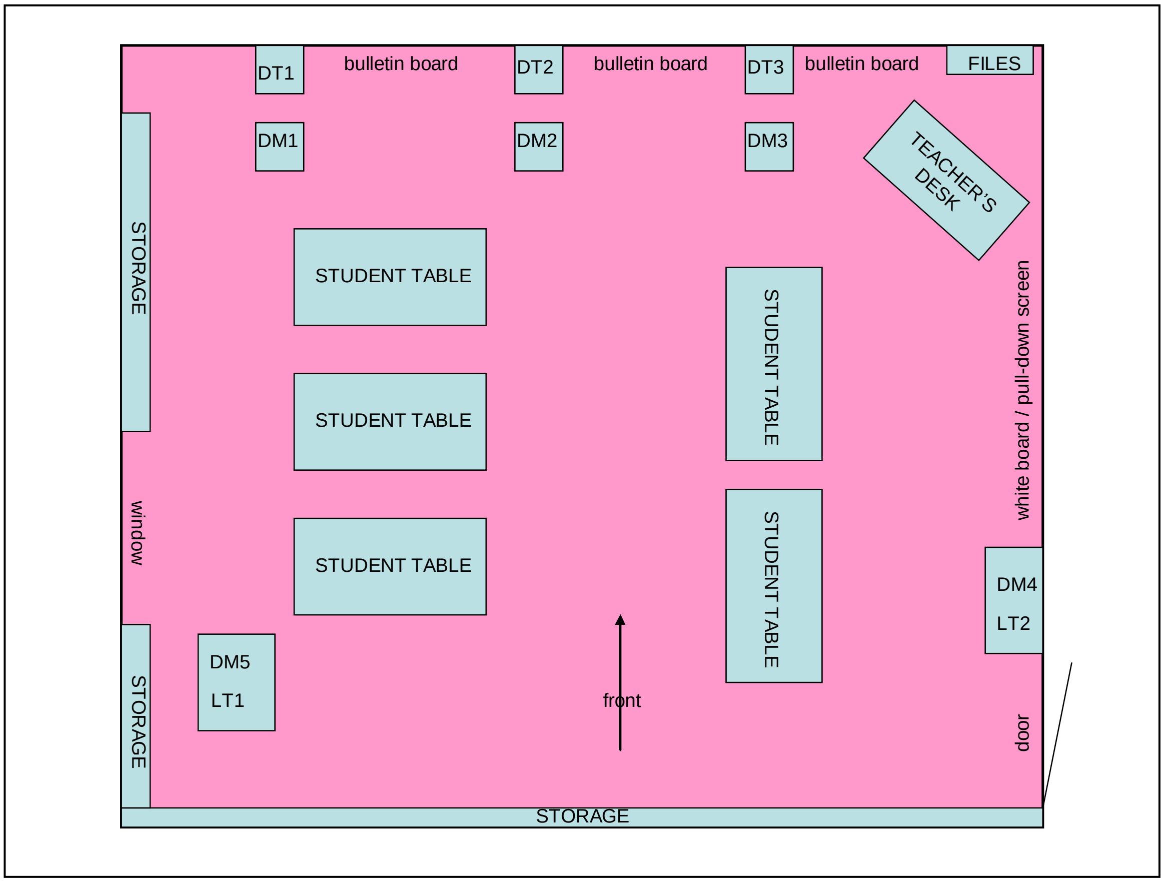
A. Classroom of Teacher E

Teacher E's enrichment classroom was located in the central part of the elementary school. Above the door, there was a sign saying "Welcome." In the front of the room, a large sign said "Wild about learning." Posters in the room said: "Learning knows no boundaries," Smiles are contagious," and "Pull together." Other posters included natural patters and designs, large symmetrical figures resembling huge snowflakes, and large cut-out figures of smiling children.

Figure C1 shows the general organization of the classroom during the period of this study. There were five student tables, which seated two or more students each, in the room in the place of standard school desks. There was a white board on one wall of the classroom and on another wall there were three bulletin boards with student information on them. There were bins of supplies and materials for various enrichment labs such as crystals, rocks, and insects. The classroom contained numerous shelves and filing cabinets.

During digital microscopy lessons, as many as eight digital microscopes, which were kept in plastic bins along with all their related materials, were brought out and set up for the lesson. In the front of the classroom, there were three small work stations desk-top computers. These were connected to digital microscopes, which were placed on small tables in front of the work stations. In the back part of the room, there were two more portable work stations, each with a laptop computer and a digital microscope. If additional microscopes were used, they were set up on one or more student tables and connected to additional laptop computers.

During some digital microscopy lessons, Teacher E arranged to have her class meet for these lessons in the school's computer laboratory. Digital microscopes were moved to that location and connected to the desk-top computers in that location. A separate description of the computer laboratory follows (see item 3 below).



Source: Reference materials in E-NB1-1 and digital file E-DFF-2004-03-08b.

Figure C1. Sketch of the Classroom of Teacher E: DT = Desk-top Computer; LT = Laptop Computer; DM = Digital Microscope.

B. Classroom of Teacher A

The classroom was located at the beginning of a corridor in the first-grade wing of the elementary school. The entrance to this wing was inviting to students and visitors because of the abundant student art work on display. There was a wing that went to the left, and there was an entrance to the main lounge and then the office to the right. As one entered the wing where the art room was located there were three-dimensional models of a variety of sporting equipment and balls, such as soccer and basketball and football, which were hanging from the ceiling leading to this wing. To the right on the bulletin board and to the left on the opposite wall were displays of figures in history. The next bulletin board on the right and just outside the art room door was a collection of pastel positive and negative snowflakes. The title drew one into the collection of individually made snowflakes. Teacher A used the bulletin board not only for viewing student work but also for connecting elements of art and principles of design to the display.

Surrounding the door to the room the theme was clear and appropriate. The theme of sports and art history were intermingled to a very innovative display of famous artists in history drawn as participating in a sport. There was a poster of Picasso as a referee, a swimmer, a basketball player, tennis player, to name a few. Above the cartoons were the actual paintings and artists' names and the title reads "Teaming up for art – join the artists." Also, much student art was on display in the room.

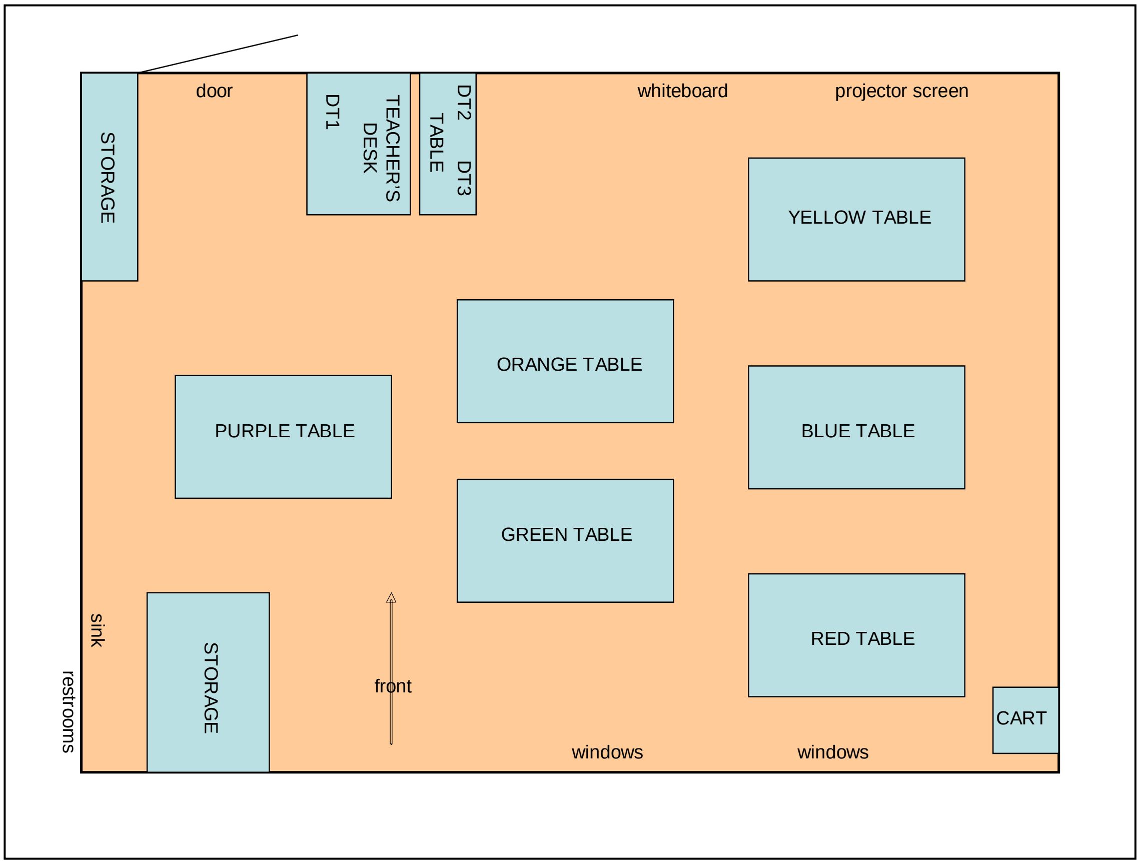
This bulletin board display nicely captured the yearly theme and the commitment of this teacher to incorporating the study of artists into the curriculum. Even the curtains with sports balls and equipment as a design on the door to the classroom and the sports equipment below the teacher's name tied into the theme and the curriculum.

As one entered the room one was immediately aware of the variety of lessons that are being taught. From art work on drying racks and an entire bookshelf lined with completed student work it was obvious that this room was used in a variety of ways. There were words of the week that welcomed the student but this time they took on an artistic flare that showed that this teacher knew that students needed multiple exposures to words in a variety of contexts to enable understanding. This was a school-wide effort and the words are reinforced throughout the building and individual rooms and not just their homeroom classrooms.

Figure C2 shows the general organization of the classroom during the period of this study. The teacher's desk was located near the door. There was a desk-top computer on the teacher desk as well as two more desk-top computers with printers on a table adjoining the front of the teacher's desk. These computers were connected to the Internet as well as the school-wide network. There were six large tables in the classroom for art lessons instead of individual desks. These tables were arranged about the room with blue stackable chairs surrounding the tables.

The way the room was arranged there was easy access to all the boards some of which were bulletin boards displaying student work in progress as well as white boards that display instructions on how to do an art lesson. The one to the right showed three circles set up like a snowman and gave instruction on how to do shading. Then there were the examples of the snowmen in a variety of colors and shading. There was a display of the ‘*Starry Night*’ and student drawings of this famous painting. As one walked into the room and across the room, there was a bookcase arranged in such a way that it created a small alcove where students’ work can be stored and kept out of the way. In front of this was the drying rack, which in itself looked like a part of the art in the room. This created a ‘work in progress’ look to the classroom and gave the room movement. The back of this corridor and the far right corner, as one looked into the room, was where the lavatories were located. There was a bulletin board facing the back of the room and a place for the storage of poster paints. There was a portable utility cart and a storage area on the back wall. The bright red bulletin board to the right of the utility area added vibrancy to the room. Below it were two file cabinets and two lengthwise storage areas that had sliding doors in front of them. There was another utility cart and a globe that stood out in front of the red background. In front of this bulletin board and storage area was a sink with the usual supply of soap and paper towels and even a step stool nearby. Adjacent to the sink were small male and female student restrooms.

During some digital microscopy lessons, Teacher A arranged to have her class meet for these lessons in the school’s computer laboratory. Digital microscopes were moved to that location and connected to the desk-top computers in that location. A separate description of the computer laboratory follows (see item 3 below).



Source: Reference materials in A-NB1-1 and digital file A-DFF-2006-01-10.

Figure C2. Sketch of the Classroom of Teacher A; DT = Desk-top Computer.

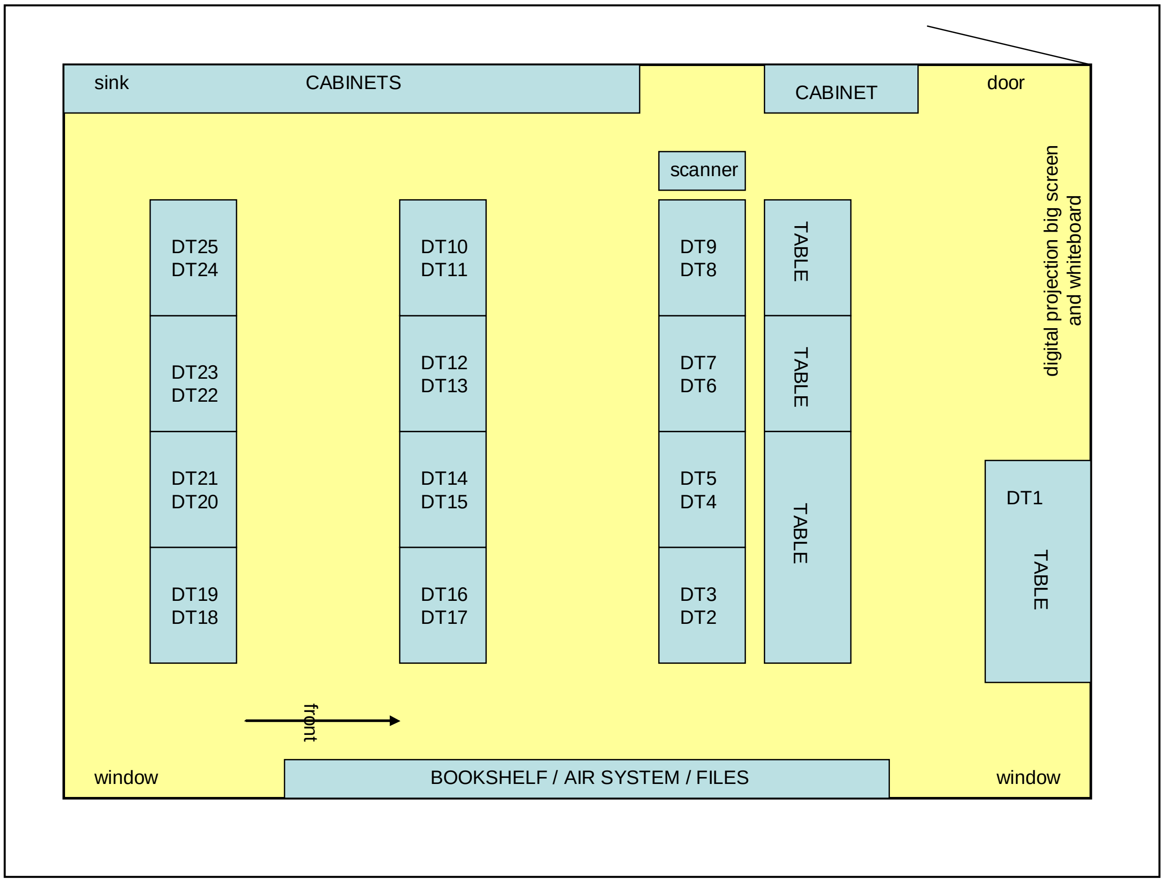
C. School's Computer Laboratory

The school's computer laboratory is located near the classrooms of Teacher E and Teacher A. Time in the computer laboratory must be arranged in advance by any teacher using the laboratory room.

The computer laboratory room is packed with computer equipment, but it is an inviting place for children to work. There is a banner at the front of the laboratory room saying "Never settle for less than your best." This is surrounded by figures of smiling children. There are numerous posters and cut outs adorning the walls, including figures of children and animals doing interesting activities. Other posters include parts of the computer, the computer's keyboard, and things to know about computers. Large windows on one side of the room add natural light to the laboratory room and prevent the room having a closed-in feeling.

Figure C3 shows general organization of the laboratory room during the period of this study. At the front of the room is a table that contains a main desk-top computer. Adjacent to the table is the main display screen for the ceiling-mounted digital projector and a large white board. Behind three tables arranged across the front of the room are three rows of four adjacent tables containing two desk-top computers each. The tables are placed touching one another so there is no space between them. Two chairs per table are placed one in front of each computer. There is room on each table top to place one digital microscope per computer. There are twenty-four desktop computers in the laboratory room, which are distributed evenly over three rows of four tables each. Also in the laboratory room are several storage cabinets and a flat-bed scanner on a portable cart. At the rear of the room, there is another large white board.

The teacher can work from the front of the room at the main table with desk-top computer, or the teacher has the option to work from other places in the room, for example, the rear of the room. The teacher's computer can connect to the digital projector. In this way, the teacher can display what is on the teacher's computer screen to the big screen in the room. There is also a Sympodium device in the room for the teacher to use for instruction.



Source: Reference materials in E-NB1-1 and digital files E-DFF-2005-11-22 and A-DFF-2006-05-01.

Figure C3. Sketch of the Computer Laboratory; DT = Desk-top Computer

APPENDIX D

INVENTORY OF RESEARCHER'S DATA ARCHIVES

The outline that follows shows the organization of this appendix. Data sources cited in this study use a "reference code," which is also used below. An example of a reference code for a digital folder and file (DFF) is E-DFF-2004-05-10, which means the digital file or folder contains digital images or videos pertaining to Teacher E, which were made on May 10, 2004. A descriptor phrase for materials archived in the DFFs is given at right of the reference codes below. An example of a reference code for notebooks (containing hardcopy (paper) notes, documents, transcripts, etc.) is A-NB1-4, which means Teacher A's notebook number 1, tab number 4. A descriptor phrase for materials archived in notebooks is given at right of the reference codes below. Specific tab descriptors for each notebook are on file with the researcher.

Following the outline, Table D1 gives dates of interviews and classroom observations in the form of a time line.

I. Digital folders and files (DFF)

A. Teacher E

E-DFF-2004-03-08a – Crystal lesson in classroom and related digital folders

E-DFF-2004-03-08b – Students exploring digital microscopy in the classroom

E-DFF-2004-03-10 – Natural objects and digital microscopes in bins

E-DFF-2004-04-19 – Crystal-growing lesson set up in classroom

E-DFF-2004-05-07 – Teacher-provided scans of student sketches from crystal lesson

E-DFF-2004-05-14 – Crystal lesson showing students working in classroom

E-DFF-2005-11-22 – Computer laboratory with digital microscopes

E-DFF-2005-12-07a – Currency lesson in computer laboratory

E-DFF-2005-12-07b – Currency pictures from ion.eas.asu.edu

E-DFF-2005-12-08 – Coins lesson in computer laboratory

B. Teacher A

A-DFF-2004-03-26 – Teacher-provided samples of student work in style of O'Keeffe

A-DFF-2004-05-04 – Flowers and shells in art lesson in computer laboratory

A-DFF-2004-05-05 – O'Keeffe art lesson in computer laboratory

A-DFF-2004-05-11 – Teacher-provided samples of student work with flowers

A-DFF-2004-05-12 – O'Keeffe art lesson in computer laboratory

A-DFF-2004-05-13a – Art lessons with digital imagery in classroom

A-DFF-2004-05-13b – Teacher-provided examples of student's work in O'Keeffe lesson

A-DFF-2004-05-17a – Art lessons using digital imagery in classroom

A-DFF-2004-05-17b – Students working on art lesson in classroom

A-DFF-2004-05-18 – Students working on art lesson in classroom

A-DFF-2004-05-various – Compilation of photos from digital folders of Teacher A

A-DFF-2006-01-10 – Photos of the art classroom of Teacher A

A-DFF-2006-05-01 – Students working on O'Keeffe lesson in computer laboratory

A-DFF-2006-05-03 – Students working on O'Keeffe lesson in computer laboratory

A-DFF-2006-05-11 – Students working on O'Keeffe lesson in computer laboratory

A-DFF-2006-05-12 – Materials for O'Keeffe art lesson in computer laboratory

II. Notebooks (NB)

A. Teacher E

E-NB1 – Researcher notes and documents related to teacher background, classroom sketches, surveys and questionnaires, classroom observations, etc. for the period 2004-2006

E-NB2 – Transcripts of interviews (pre-interview 2004, post-interview 2004, post-interview 2006, interview after first lesson 2004, and interview after lessons 2006, etc.)

E-NB3 – Interviews coded for semantic domain analysis and sorted by category

E-NB4 – All additional paper documents, etc.

B. Teacher A

A-NB1 – Researcher notes and documents related to teacher background, classroom sketches, surveys and questionnaires, classroom observations, etc. for the period 2004-2006

A-NB2 – Transcripts of interviews (pre-interview 2004, post-interview 2004, post-interview 2006, interview after first lesson 2004, interview after lessons 2006, etc.)

A-NB3 – Interviews coded for semantic domain analysis and sorted by category

A-NB4 – All additional paper documents, etc.

C. Researcher

R-NB1 – Researcher's correspondence and documents related to the Institutional Review Board requirements of this study.

R-NB2 – Researcher's notes and documents not included in Teacher E or A notebooks.

R-NB3 – All additional paper documents, etc.

Table D1

Dates of Interviews and Classroom Observations

Teacher	*Name and dates of interviews*	*Dates of classroom observations*
Teacher E	Pre-interview 2004	
	March 1, 2004	
		March 8, 2004
	Interview after first lesson 2004	March 10, 2004
	March 10, 2004	
		April 19, 2004
		April 26, 2004
		May 7, 2004
		May 11, 2004
		May 14, 2004
	Post-interview 2004	
	June 15, 2004	
		October 15, 2004
		November 22, 2004
		December 7, 2005
		December 8, 2005
		December 9, 2005

Teacher	*Name and dates of interviews*	*Dates of classroom observations*
	Post-interview 2006	April 12, 2006
	April 12 and 13, 2006	
	Interview after lessons 2006	
	April 12, 2006	
	Interview about conference	
	April 13, 2006	
Teacher A	Pre-interview 2004	
	March 1, 2004	
	Interview after first lesson 2004	March 26, 2004
	March 26, 2004	
		May 4, 2004
		May 5, 2004
		May 11, 2004
		May 12, 2004
		May 13, 2004
		May 17, 2004
		May 18, 2004

Teacher	*Name and dates of interviews*	*Dates of classroom observations*
	Post-interview 2004	
	July 20, 2004	
		December 8, 2005
		January 6, 2006
		January 10, 2006
	Post-interview 2006	April 13, 2006
	April 13, 2006	
	Interview after lessons	
	April 13, 2006	
	Interview about conference	
	April 13, 2006	
		May 1, 2006
		May 2, 2006
		May 3, 2006
		May 4, 2006
		May 11, 2006
		May 12, 2006