Examining Assessment Methods in Project-Based Mathematics Learning

by

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Abstract

Project-based learning (PBL) is an instructional method that has grown in popularity across all grade levels and subject areas, in both K-12 schools and higher education institutions. PBL embraces the integration of curriculum across subjects, the engagement of home and community in school learning, and the involvement of students in cooperative teamwork (Harada, Kirio, & Yamamoto, 2008). With regard to mathematics, specifically, advocates of project-based learning claim that problem solving skills are successfully developed when students learn mathematical content and process knowledge on their own in an authentic setting (Roh, 2003).

This method of instruction has been adopted at a newly created public K-9 school system in its second year of operation in central Alabama. This study utilized a mixed methods approach (Creswell & Clark, 2017) to examining the implementation and assessment methods of project-based mathematics learning taking place in the middle grade levels (6-8) of this particular school system. In order to examine project-based learning implementation and assessment in middle grades mathematics classrooms in the school system of interest, data collection included student pre- and post-semester surveys, teacher post-semester surveys, multiple classroom observations, and existing data in the form of classroom grades and standardized test scores provided to the researcher by the school. The primary survey instrument utilized for this study was the Attitudes Toward Mathematics Inventory (Tapia & Marsh, 2004).

The population of interest was 6th, 7th, and 8th grade mathematics students and teachers at the selected school system currently implementing and participating in project-based learning in mathematics classes. Research questions focused on topics such as: implementation and assessment of project-based mathematics learning; comparisons of classroom performance grading systems and standardized test results; relationships between student self-assessments, grades, and standardized test scores; and looking to identify significant increases in students' levels of self-confidence, value, enjoyment, and motivation in mathematics. Findings show that project-based learning is being implemented at different levels across the middle grades mathematics classes of the school. Some agreement was found between various assessment methods, but no significant increases were found in students' mathematics self-confidence, value, enjoyment, or motivation.

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Chapter I

Introduction

Project-based learning (PBL) has recently come into prominence as a prevalent method of instruction for a variety of subjects and grade levels in K-12 schools. PBL has also been implemented in some subject areas in higher education. Marzano (2003) states that research supports a move from *memorized* learning to *memorable* learning. These memorable learning experiences promote mastery of both the content and the process. PBL embraces the integration of curriculum across subjects, the engagement of home and community in school learning, and the involvement of students in cooperative teamwork (Harada, Kirio, & Yamamoto, 2008). With regard to mathematics, specifically, advocates of project-based learning claim that problem solving skills are successfully developed when students learn mathematical content and process knowledge on their own in an authentic setting (Roh, 2003). Mathematics PBL has also become more prevalent since it has been found to decrease achievement gaps, with low performing students showing particularly high growth rates on mathematics scores (Han, Capraro, & Capraro, 2015).

This method of instruction has been adopted at a newly created public K-9 school system in its second year of operation in central Alabama. After one full year of instruction using a project-based approach, educators and school administrators stand to benefit from an examination of their assessment methods in terms of how effectively they are measuring the outcomes of project-based learning – specifically in mathematics classes. At the time of this study, the school system sought to examine the extent to which project-based learning was being implemented and appropriate assessment methods were being used. This study utilized a mixed methods approach (Creswell & Clark, 2017) to examining the implementation and assessment methods of project-based mathematics learning taking place in the middle grade levels (6-8) of this particular school system.

Research Questions

Research questions for the study included the following:

- RQ1: How is project-based mathematics learning currently being implemented and assessed?
- RQ2a: How does the school's classroom performance grading system compare to standardized test results?
- RQ2b: How do student self-assessments relate to grades and scores on standardized tests?
- RQ3: Does project-based learning lead to increases in students' levels of self-confidence, value, enjoyment, and motivation in mathematics?

Background

The school system at the center of this study operates with the goal of creating a culture of intellectual curiosity, where all students have ownership over their learning and are inspired to think, innovate, and create. This goal is at the forefront of all teaching and learning activities each day. The school system has adopted the idea of "The (School Name) Way," which emphasizes the strong desire to create an environment rooted in intellectual curiosity. The Schools' mission, vision, and beliefs give evidence of the climate and culture that the Schools strive to maintain (Mission, Beliefs, and Vision, 2016). This culture includes intellectual curiosity, genuine engagement, and meaningful learning with the aim of solving real problems for a real audience. The full text of the Mission, Beliefs, and Vision is presented in Appendix A.

Significance

This research study will enable the school system to make data-driven decisions regarding their use of PBL learning in mathematics and their chosen assessment methods. This study will help school leaders determine whether or not current assessment methods are valid in measuring students' levels of understanding and concept mastery, hopefully leading to the development of more meaningful assessment methods and overall school improvement/enhancement. Current assessment methods include monitoring of progress and capturing outcomes using a standards-based reporting tool called FreshGrade, which is available online to parents and students and reports learner progress using various colors instead of percentages or letter grades. Culminating exhibitions and showcases after big projects allow students to demonstrate and share their learning with an authentic audience. Ongoing feedback and critiques also take place throughout projects, allowing students to reflect on their learning and include these reflections in project portfolios. Focus groups are regularly conducted with students, and metrics such as ACT Aspire scores and Advanced Placement (AP) scores are considered as secondary assessment metrics (Assessment of Learning, 2016).

Results will ultimately help the profession by providing valuable information to educators in similar settings, namely mathematics classrooms in rural public schools, and providing teachers and school administrators with a better understanding of how mathematics PBL assessments reflect student learning.

Assumptions

Assumptions made by the researcher in this study included the following:

- Middle school mathematics teachers in the school system will implement project-based learning teaching methods in their classrooms.
- Teachers have received professional development through pre-semester workshops and conferences focusing on project-based learning instructional methods and integrating cross-subject content into their classes.
- Students in the school system will actively participate in project-based learning instruction and activities.
- PBL teaching methods will be applied with a high level of fidelity of implementation.
- Existing data such as standardized test scores and classroom grades are valid and reliable records that contain accurate student information.

Challenges

One challenge of this study is the separation of extraneous variables that may indirectly influence the outcomes of project-based mathematics learning. Factors such as teacher quality, student demographics, aptitude, prior math achievement, socio-economic status, and language ability could all be potential covariates that need to be considered.

Another challenge was acquiring parental consent/student assent for a large enough number of students to be conducive to a meaningful study. An explanation of the study by the researcher to each class at the beginning of the semester was given in order to address this challenge, along with cooperation from classroom teachers who assisted in the collection of permission forms.

Limitations

Because this project takes on a mixed methods approach with some aspects of a case study approach in order to generate an in-depth, multi-faceted understanding of the project-based learning assessments taking place at the school, one limitation of the study is a lack of comparison data from another school system. The school system involved in this study is very unique in terms of its approach to learning, instructional methods, and student demographics. The standardized test scores, classroom grades, classroom observations, student/teacher surveys, and existing data records used in this study are exclusive to one school system. Another limitation of the study is the relatively short time frame – surveys took place over the span of just over one semester (August to January) and classroom grades were obtained over the span of the first three nine-week grading periods of the academic year.

Hypotheses

The following hypotheses are proposed:

- Effective project-based mathematics learning instruction and assessment methods are being incorporated in mathematics classes of the middle grade levels of the school system.
- Students' standardized test scores in mathematics will <u>not</u> have a high correlation with their classroom mathematics grades because of inconsistencies between knowledge measured by test items and the learning outcomes achieved by PBL. A weak positive correlation is expected.
- Students' self-assessments (survey responses) and teacher assessments (grades) of their mathematical content knowledge are expected to have a strong positive correlation.

- Students' levels of self-confidence, value, enjoyment, and motivation in mathematics will significantly increase after one semester of participation in project-based learning.

Chapter II

Literature Review

Theory

Project-based learning is grounded in the constructivist theory that students understand material more thoroughly when they actively work with and use their own ideas (Krajcik & Blumenfeld, 2006). In terms of mathematics, proponents of mathematical problem solving believe that students successfully develop the skill of problem solving when they learn mathematical knowledge on their own, in a heuristic manner (Roh, 2003).

As a broad model, PBL was developed in the medical field for the purpose of giving future doctors real-life “practice” with patients and in laboratory settings (Savery & Duffy, 1995). Since its beginning, it has been expanded to a variety of subject areas and is used in classrooms ranging from elementary schools to universities and professional schools. Students participating in project-based learning work in groups and are involved in solving challenging problems that are authentic to the real world, curriculum-based, and often interdisciplinary (Solomon, 2003).

The basis for PBL is rooted in the cognitive constructivist learning theories of Dewey and Piaget. Dewey (1986) says that education takes place through a series of practical and theoretical problematic struggles, which are resolved by the student engaging in a process that leads to learning through reorganization of their thoughts. Piaget (1977) describes the process as the need for accommodation when current experience cannot be assimilated into the learner’s existing schema. In terms of PBL, these conflicts and questions within the student serve as the stimulus for learning and determine the organization and nature of what is learned (Savery & Duffy, 1995). In other words, the goals of the learner and the questions that they deem worthy of answering are essential in considering what will be learned. Once goals for learning are established, knowledge evolves through social negotiation and the ever-changing individual understandings held by students in the group, classroom, school, community, etc.

The social constructivist theories of Vygotsky and his idea of scaffolding are also instrumental in the theoretical basis for PBL. "What the child is able to do in collaboration today, he will be able to do independently tomorrow." (Vygotsky, 1934/1987). By collaborating with teachers and classmates, students are able to increase their levels of understanding, problem solving, and mathematical skills. The social constructivism of Vygotsky presents itself in PBL through acculturation, learning experiences reflecting real-world complexities, the presence of a more knowledgeable other (which could be the classroom teacher or a peer), and the zone of proximal development (ZPD). The ZPD is utilized in project-based learning when the student is placed in a role or situation that challenges them to advance their understanding of a topic through the support and assistance of others (Voth, 2014).

Students require a great deal of support and monitoring as they navigate the twists and turns of discovering how to best solve their given problem. Scaffolding occurs in PBL when teachers help students bridge the gaps between their existing knowledge and skills and the necessary knowledge and skills to complete the task at hand. This scaffolding is temporary, and as students gain understanding and ability, they develop into self-confident and capable learners (Bell, 2010).

Savery and Duffy (1995) describe problem-based learning as "what we consider to be one of the best exemplars of a constructivist learning environment" (p. 31). They point out that what is learned by students cannot be considered separately from *how* it is learned – students' interactions with their environments are the channel through which understanding is established, again pointing to the importance of constructivist theory in this method of instruction.

Overview of PBL Methods

Before discussing the methods used in PBL instruction, it is important to make note of an issue regarding terminology. Throughout the literature, the acronym PBL refers alternatively to either project-based learning or problem-based learning. The differences between the two methods are subtle, and many times are considered to be one and the same. Projects are sometimes viewed as smaller tasks with specifications for a desired end product (Savery, 2006), which lead to solutions of the bigger issue, the problem. The literature reviewed here includes studies in both project-based and problem-based learning.

It is helpful to note that PBL is neither a Socratic process of simply inquiry and discussion, nor a discovery learning environment where a pre-determined outcome is desired by the teacher (Savery & Duffy, 1995). PBL projects differ from traditional school projects in that they incorporate more student autonomy, a greater degree of student choice, more work time is unsupervised, and students have more responsibility (Thomas, 2000).

This method of learning is more in-depth, more student-focused, and more dependent on the active engagement of students as they construct their own understandings in a context similar to the real-life situation where their knowledge will be applied. Student learning is inherently valuable in its own right, because it has a connection to something real, not just test scores or grade point averages (Solomon, 2003). Student choice is another key element of PBL, as learners pursue knowledge by asking questions and exploring topics that have piqued their natural curiosity. Many of these inquiries arise from scientific observations or interest in current social problems (Bell, 2010).

Implementation

In one model of project-based instruction developed with the aim of assisting middle school science teachers, the following five elements are considered essential (Krajcik, Blumenfeld, Marx, & Soloway, 1994):

1. Projects engage students in investigating an authentic question or problem.
2. Students develop a series of artifacts, or products, that address the question/problem.
3. Students are engaged in investigations.
4. Students, teachers, and members of society are involved in a community of inquiry and collaboration.
5. Projects promote the use of cognitive tools by students.

The model focuses on the back-and-forth of collaboration, enactment, and reflection, and these elements capture the intentions and fundamental aspects of PBL with regard to the roles of students, teachers, others in the community, and the projects themselves.

Specific to mathematics, the following desirable features for problem-solving approaches are listed by Henningsen and Stein (as cited in Erickson, 1999):

1. Problems are genuine and reflect the goals of school mathematics.
2. Situations motivate students and consider their interests and experiences, local contexts, puzzles, and applications.
3. Tasks are interesting and have multiple solution strategies, multiple representations, and multiple solutions.

4. Problems provide rich opportunities for mathematical communication.
5. Appropriate content is covered and students' ability levels and prior knowledge are considered.
6. Difficulty levels are reasonable, and students are challenged but not discouraged.

These problems are described as taking anywhere from a few minutes to a few weeks to solve, indicating that a wide variety of difficulty levels, scales, and types of problems are suitable for the PBL approach.

PBL instruction must have learning-appropriate goals. When learners are given project-based tasks, it is important for teachers to keep in mind that the difficulty of the projects, or even the types of the projects, must not necessarily be the same as those that adult professionals would deal with. What is important, rather, is that the types of cognitive demands and challenges presented should reflect real-life scientific activities and should be consistent with the real-world environment for which students are being prepared (Savery & Duffy, 1995).

The role of a teacher in a PBL classroom is not the same as the role of a teacher in a traditional classroom. Rather than being the "giver" of knowledge, teachers using PBL strategies serve more as facilitators. The facilitator has a major responsibility to foster the learning environment and guide students in their activities and decision making processes. Another important function of the facilitator is to model the metacognitive thinking that students should engage in throughout the problem solving process (Savery & Duffy, 1995).

Academic Benefits

The benefits of PBL instruction in terms of knowledge acquisition and retention have been demonstrated in numerous studies. In a 1998 experimental research study, Boaler presents results showing that students in traditional content-based learning mathematics classrooms demonstrated lower achievement on both standardized tests and project-based tests when compared to students who had learned through a PBL mathematics approach. Students from the PBL classrooms recognized that mathematics involved active and flexible thinking, and they were successful in adapting the methods they had learned when necessary for solving a new problem. The project-based tests these students took involved realistic situations, implying that PBL instruction gives students an understanding that is able to be retained and later applied to authentic circumstances. The students from the traditional classroom had difficulty using the information they had learned in anything other than textbook questions. Boaler (1998) points out that the students from the PBL approach did not necessarily know *more* mathematics than the students from the traditional approach, but they were better able to use their knowledge because of three characteristics: a willingness and ability to perceive and interpret different situations; a sufficient procedural understanding to allow them to select an appropriate procedure; and a mathematical confidence that enabled students to adapt and change procedures when a new situation called for changes. This indicates that students receiving PBL instruction acquire not only more translatable knowledge, but a different kind of knowledge than that acquired by students in a traditional approach (Bell, 2010).

In addition to performing better when presented with real life problem solving tasks, students also find more enjoyment in the PBL model of instruction. Savery (2006) reports that in one study involving physical therapy students, program graduates performed equally well with PBL or traditional instruction approaches, but students reported a preference for the PBL approach.

Project-based learning as the approach to instruction has greater benefits to students than simply adding on projects as extra assignments or supplements to traditional instruction. Krajcik and Blumenfeld (2006) describe many traditional experiments and projects as being “cookbook” procedures, where students follow a prescribed set of steps to reach a predetermined outcome or conclusion. This process does not require a deep understanding of material, and the learning that results is superficial. In a project-based classroom, however, students are allowed to “explore phenomena, investigate questions, discuss their ideas, challenge the ideas of others, and try out new ideas. Research shows that problem-based science has the potential to help all students – regardless of culture, race, or gender – engage in and learn science” (Project-Based Science section, para. 2).

Lipka et al. (2005) present a case study of a culturally based mathematics curriculum among Native Alaskan students. Students were engaged in projects that reflected themes and connections to their local culture. They state that, “The need for culturally based curricula seems obvious to those in the field of educational anthropology, but not necessarily to policy makers.” They found the culturally-based mathematics project to allow student ownership through inquiry and cultural connections, and they present strong evidence that this project-based curriculum is beneficial in improving students’ academic performance both statistically and practically. The real and positive connections engage students in deeper levels of engagement and understanding.

Schneider, Krajcik, Marx, and Soloway (2002) address the concern that has been raised by some that movement away from teacher-disseminated information will limit the amount of content to which students will be exposed, therefore giving students a disadvantage when taking important achievement tests. Their study finds that among tenth and eleventh grade students enrolled in a PBL science program, when compared to subgroups, the PBL students outscored the national sample on 44% of test items on the NAEP science test, showing that students participating in project-based learning are well prepared for this type of test. These outcomes should translate to project-based learning in mathematics classes.

Although standardized test scores are often used to bolster claims of the success of PBL, it is important to recognize that PBL fosters the development of many twenty-first-century skills that cannot be measured on a standardized test (Bell, 2010). Self-management, teamwork, leadership, and working to solve real tasks in real environments are crucial in the professional world (Zafirov, 2013), and PBL prepares students to successfully collaborate, negotiate, plan, and organize. Other benefits to students include increased social and communication skills and more clear realizations of interdisciplinary connections in subject areas (Railsback, 2002). While rubrics, self-evaluations, and reflections can somewhat address these factors, the benefits of PBL reach far beyond the singular value of a standardized test score.

In mathematics, students are pushed beyond the traditional goal of computational ability and are required to communicate effectively both the solutions and the solution paths, therefore demonstrating deeper levels of understanding. Students can generate more specific questions based on the original problem and then explore strategies for finding a solution. Throughout the problem-solving tasks, students can also come to see the value of mistakes in mathematics – dead ends and wrong turns in mathematics are often just as instructive as correct solutions in helping students understand the mathematics involved (Erickson, 1999).

Maximizing Impact: Student, Teacher, and Classroom Factors

The effectiveness of PBL depends on student characteristics, teacher characteristics, the overall classroom and school environments, and the specific tasks performed by the learners. With regard to students themselves, a number of characteristics can be considered: age, gender, learning style, attitude and disposition, race/ethnicity, socioeconomic status, ability, etc. These factors must be considered as covariates in the study, possibly impacting learning outcomes and correlations between formal assessment findings and observed outcomes and students' self-ratings of learning outcomes. Thomas (2000) discusses multiple studies on the outcomes of PBL dependent on student factors: Findings include evidence that students with lower ability benefit more and demonstrated the largest gain in critical thinking and social participation behaviors. Girls were found to show a preference for teaching methods that stress understanding rather than memorization and rote learning procedures, indicating that exposure to PBL may raise the mathematical achievements of all students, but especially girls. Students who do not perform well in traditional classrooms may have learning styles and preferences that are not well-suited to the transmission of facts and rote learning processes, but may thrive in a PBL environment.

In PBL classrooms, teachers' instructional abilities are more critical than in traditional classrooms. PBL teachers must develop a broader range of pedagogical skills in order to be effective – these skills are critically important as the teacher must convey to the students not only mathematical knowledge, but also knowledge of mathematical processes, communication and presentation skills, modeling, and reasoning (Roh, 2003). Therefore, professional development and teacher adaptation are critical elements to successful project-based learning.

School factors can present constraints on the success of project-based instruction: PBL is more likely to be successful in schools with adequate resources, flexible schedules, compatible technology, manageable class sizes, and supportive curricular policy (Thomas, 2000). These conditions are generally favorable at the school system at the center of this study: resources, schedules, technology, and curricular policies are all in place to support PBL. Manageable class size is an area where the school is currently struggling, with population growth and school enrollment increasing faster than originally expected and planned for. Hertzog (1994) reported that school factors were the primary barrier in the implementation of project-based learning – especially physical organization of the school, limitations on available time, and structure of schedules to cover all academic subjects (as cited in Thomas, 2000, p. 26-27).

Motivation, Self-Efficacy, and Interest

Evidence from prior studies shows that PBL proves beneficial to students by helping them develop flexible understandings of information and the continued ability and desire for lifelong learning. Improved student motivation, specifically intrinsic motivation, is considered to be one of the major advantages of PBL (Hmelo-Silver, 2004). This intrinsic motivation is increased because when students assume the role of a scientist, historian, engineer, or another individual who has a real stake in the proposed problem, students take ownership and feel invested in the problem (Stepein & Gallagher, 1993).

Another possible explanation for increased motivation is accountability. When students are completing a project in a group, they are all functioning as members of a team. Children often do not want to let their friends down, and this accountability to peers can have greater consequences and provide more motivation to students than if they were only responsible to the teacher (Bell, 2010).

The following conditions are decreased in a PBL environment, which can lead to increases in intrinsic motivation (Stiggins, Arter, Chappuis, & Chappuis, 2007):

- Intimidation
- Punishments and rewards linked to subjective judgments
- Comparisons of students to their peers
- Infrequent or vague feedback
- Limited personal control

- Responsibility without authority

In PBL classrooms, these conditions are replaced with student sense of control and choice, frequent and specific feedback, challenging but not threatening tasks, accurate self-assessment, and learning tasks relevant to the student's everyday life.

Questions about student motivation are often considered separately from questions about thinking and learning, but teachers are required to integrate these two areas (Blumenfeld et al., 1991). Classroom activities comprised of predominantly low-level tasks that don't require complex thinking can contribute to poor attitudes toward learning and a lack of understanding of content and processes. The authentic projects of PBL, on the other hand, lead to increased motivation when students are focused on formulating plans, tracking progress, and evaluating solutions – not on grades and other anticipated outcomes and consequences.

Blumenfeld et al. found that the features of PBL such as variety, challenge, student choice, and realistic problems promote increased levels of interest and perceived value among students (as cited in Thomas, 2000, p. 6). Self-reports collected by teachers also showed that PBL activities resulted in a variety of benefits for students, including improvements in attitudes towards learning, work habits, problem-solving capabilities, and self-esteem. These teachers, in fact, indicated that learning subject matter content was not one of the primary benefits of project-based learning – subject matter content knowledge was rated as a less frequent type of learning in PBL than problem-solving skills, aspects of cooperation, critical thinking skills, and aspects of responsibility (Thomas, 2000). A study of participation in a scientific and technological PBL instruction found that students' levels of motivation and self-image were elevated, supporting conclusions that PBL fosters meaningful learning (Doppelt, 2003).

While PBL has been reported to increase self-esteem in students, Meyer, Turner, and Spencer (1997) point out that a sense of academic self-efficacy is required before students will actively engage in strategic problem-solving efforts. They say that students who report higher self-efficacy are expected to choose to undertake academic challenges for the purpose of improving mastery and are more likely to persist toward achieving their goals, indicating that "challenge seekers" (those with higher tolerance for failure and a learning goal orientation) will be more open to a PBL approach than "challenge avoiders" (those who have a higher negative affect for failure and a performance-based goal orientation).

Challenges

High quality implementation of PBL instruction requires a large investment of time, energy, and resources on the part of many individuals: students, parents, teachers, and school administrators. Solomon (2003) lists the following things as being essential to successful implementation of PBL: change in teachers' approaches to teaching, change in students' approaches to learning, restructuring of policy decisions, leadership, and professional development for teachers. These things are all currently in place at the school. In addition to these demands, teachers must also find ways to fit more collaboration into their schedules – with both fellow teachers and people from the community who can serve as audiences for student projects (Bradley-Levine et al., 2010). Clearly, adopting a PBL approach to instruction is not a simple decision for a school or school district. Many factors must be considered.

Another challenge of implementing PBL in K-12 schools is the constraint of traditional school day scheduling and the pressure to produce high standardized test scores. Savery (2006) says this:

> Most state-funded elementary schools, middle schools, and high schools are constrained by a state-mandated curriculum and an expectation that they will produce a uniform product. High-stakes standardized testing tends to support instructional approaches that teach to the test. These approaches focus primarily on memorization through drill and practice, and rehearsal using practice tests. The instructional day is divided into specific blocks of time and organized around subjects. There is not much room in this structure for teachers or students to immerse themselves in an engaging problem. (p. 17-18)

The challenge of the traditionally structured school day is something that has already been addressed at the school system involved in this study – their school day is not divided into the typical blocks or periods, and students have some degree of freedom to use their time working on projects and activities of their choice. This is helpful for the implementation of PBL to be more successful and impactful in the school.

When these challenges are overcome and PBL instruction is implemented, performance standards can still create difficulties in developing projects and identifying driving questions and problems. When the standards are considered before the driving question, it can be difficult to identify questions that would be meaningful and interesting to students since many driving questions do not address learning outcomes aligned to national, state, or district standards and curricula (Krajcik & Blumenfeld, 2006). Student interest and curiosity should be considered first in identifying a question or problem, and then projects can be identified that promote the appropriate cognitive skills and learning outcomes.

The integration of technology can also be a challenge in PBL. While teachers realize that it is a valuable tool for learning, they often have difficulty incorporating technology into the classroom in meaningful ways and as a cognitive tool (Thomas, 2000).

Assessment

Much of the reviewed literature focuses either on how to assess project-based learning in general, or on how to assess mathematics learning in general. There is very little research on best practices and methods for assessing project-based learning specifically in the context of mathematics instruction. However, many of the ideas and suggestions for PBL in general can be applied or slightly adapted to fit the needs of students and teachers in PBL mathematics classrooms.

Just as the instruction in a PBL classroom is authentic, Hopkins (1999) describes how mathematics assessments should also be authentic. Authentic assessment involves data collection that provides teachers credible and reliable information about what students are able to do. It is important for not only the results to be accurate, but for the process of obtaining them to be trustworthy. Authentic assessment is part of an ongoing cycle of teaching, learning, and assessment working together as an interactive process.

Solomon (2003) explains the culmination of the PBL process as follows: “At the end, students demonstrate their newly acquired knowledge and are judged by how much they’ve learned and how well they communicate it.” Although no details are offered as to how students communicate their knowledge (because different projects and contexts call for different measures), it is clear that a subjective assessment by the teacher will take place.

However, teacher input should be received by students not just at the end of a project or unit, but throughout the learning process. It is important for the teacher to have regular conversations with students to ensure that the students are staying on track in their plans and activities, and also to check that they are developing their ideas and skills fully (Bell, 2010). If time is a constraint, teachers can provide group feedback instead of feedback to individual students (Krajcik & Blumenfeld, 2006). With this regular delivery of feedback and guidance, the expertise of the teacher will benefit students throughout all stages of the project.

Throughout this cycle of assessment and revision, teachers do not specify exactly what students should change, instead they give general feedback that alerts students to the key concepts that they should rethink. Students can then return independently to portions of the project where they see opportunities for improvement, empowering them with intellectual responsibility (Barron et al., 1998).

In addition to this assessment by the teacher, student self-assessments also play a large role in the PBL instructional model. Savery (2006) recommends that both self-assessment and peer assessment be conducted after the completion of each problem or project, and again at the end of each curricular unit, so that they occur regularly throughout the project. These assessments promote reflection and metacognition skills in students.

One method of self-assessment, self-grading, is described by Ulmer (2000). He developed this self-grading practice as a solution to the excessive amounts of time required for formative assessment activities in PBL in mathematics. In this process, students are given an assignment requiring a short written response to a question. After responses are written, students engage in discussions about their perspectives on the assignment. Students correct and revise their responses as the discussions are taking place, and additions and corrections are made on their papers using a different colored pen or pencil from the one used in writing the original response. Students are given rubrics and reflect on their work, and then assign themselves a grade. By participating in this process, the learner is able to see the differences in their initial response and final response, becomes engaged in critical thinking through the discussion and revision processes, and receives timely feedback from the instructor on both the original and final responses. This improves the quality and quantity of formative assessment taking place, and the impetus to think critically is placed where it belongs – with the student, not the teacher.

Savery (2006) also discusses the goals of formal student examinations in a PBL classroom. When students are given an exam, the goal of that exam must be to measure the student's progress toward both the knowledge-based and process-based aspects of the material. Both dimensions of the PBL process should be assessed regularly, and students need to be able to recognize and communicate to others their knowledge and what and how they learned throughout the project.

Sometimes, formal exams will not be a useful measure of gains in student knowledge. Bell (2010) describes a study in which students used principles from geometry and architecture to develop designs for a new playhouse to be built at a community center. The project was assessed by the evaluation of the designs themselves, with a determination of whether or not the submissions were accurate enough to actually be built. In this particular case, 84% of the student submissions were deemed buildable, and after the assessment, students were able to consult other resources and revise their designs.

This process of revision after the initial assessment shows a level of motivation in the students created in part by the assessment process, evidencing assessment *for* learning (where assessment is not just the index of change, but rather it is the change) as opposed to merely assessment *of* learning. Research on motivation, learning strategies, and feedback all support assessment *for* learning as the best use of assessment to promote student learning (Stiggins, Arter, Chappuis, & Chappuis, 2007).

Among students who report overwhelming favor for PBL over traditional instruction, team dynamics and seemingly unfair assessment are cited as their biggest frustrations (Piper, 2012). Students can be resentful of "group grades" where everyone in a group receives the same grade for a project, regardless of whether or not equal contributions were made by all group members. To address this challenge, Piper suggests the following methods:

- Individual portfolios – students select elements from the project that they were primarily responsible for producing and then discuss why they are good examples of their skills.
- Role-based assessment – students cycle through lead and supporting roles and are graded on the artifacts produced when they are the lead, and graded on their actions to support the team when they are in supporting roles.
- Weighted scoring – a combination of self-evaluations, peer-evaluations, and teacher evaluations are used to score student contributions.

When students work together in an environment that recognizes and assesses their individual contributions, PBL can be more effective for all types of students as the teacher is enabled to help more students individually on their level.

Gaps in the Literature

As stated previously, little research exists specifically on the assessment of PBL in mathematics classrooms. In her 2004 article, Hmelo-Silver notes that minimal research has been conducted outside of the fields of medical education and gifted education.

Some research studies have examined the effectiveness of PBL through summative assessment and looked at the degree of success associated with implementation of PBL through formative assessment. However, only one study of PBL effectiveness was found that incorporated an experimental research design (Thomas, 2000). There also does not seem to be much existing literature focusing on determining the validity of the assessments themselves when conducted to measure the outcomes of project-based mathematics learning. The proposed study offers an expansion of the knowledge in this area, which will be useful to educational administrators, teachers, and policy makers.

Chapter III

Methods

In order to examine project-based learning implementation and assessment in middle grades mathematics classrooms in the school system of interest, data collection included student pre- and post-semester surveys, teacher post-semester surveys, multiple classroom observations, and existing data in the form of classroom grades and standardized test scores provided to the researcher by the school. The population of interest was 6^{th}, 7^{th}, and 8^{th} grade mathematics students and teachers at the selected school system currently implementing and participating in project-based learning in mathematics classes.

Purpose and Research Questions

This project examined the methods of implementation and assessment of project-based mathematics instruction at a newly established K-9 school located in central Alabama. Research questions and methods of analysis included the following:

- RQ1: How is project-based mathematics learning currently being implemented and assessed? (classroom observations, descriptive statistics, qualitative description)
- RQ2a: How does the school's classroom performance grading system compare to standardized test results? (Chronbach's Alpha, Kendall's Coefficient of Concordance W, Pearson correlations)
- RQ2b: How do student self-assessments relate to grades and scores on standardized tests? (Chronbach's Alpha, Kendall's Coefficient of Concordance W, Pearson correlations)

- RQ3: Does project-based learning lead to increases in students' levels of self-confidence, value, enjoyment, and motivation in mathematics? (paired samples T-tests, pre-post mean differences)

Setting

The school system involved in this study is a non-traditional public school system in central Alabama. The system is unique in that it did not stem from a pre-existing system, school, policies, or culture. It was created to serve a new municipality with a rapidly growing population, which has many elements of a suburban community but is also largely rural. The percentage of students living in poverty in this school system is far lower than the percentages for other public schools in the same county. Challenges faced by this newly established school system have included increased enrollments stretching the availability of space and resources, the ability to effectively communicate the non-traditional grading and assessment practices of the system, and using data analysis to drive instruction and the implementation of instructional programs, policies, and procedures (Advance Education, 2017).

Research Design

The design for this study was a mixed-methods approach utilizing existing data (academic performance information including standardized test scores and classroom performance ratings) and new data obtained through classroom observations, student surveys, and teacher surveys. Students' mathematical abilities were measured by their classroom grades, standardized test scores, and survey responses, collected periodically throughout the semester from the classroom teachers and the students.

Students' mathematics self-confidence, value, enjoyment, and motivation were measured by online surveys administered once in September 2016 and once in January 2017 through

Qualtrics software. These surveys included the Attitudes Toward Mathematics Inventory (ATMI) (see Appendix B) and supplemental questions developed by the researcher (see Appendix C). Teacher surveys were conducted after the conclusion of the Fall 2016 semester, in January 2017. The teacher surveys collected information about how well teachers feel that they are able to determine their students' mathematical knowledge through the use of class-wide, small group, and individual projects or assignments; teacher attitudes about the importance of teaching pure and applied mathematics; and the perceived availability of opportunities for students to express their understanding of mathematical concepts through oral, written, and other creative outlets. The full teacher survey instrument is included in Appendix D. Other classroom factors that determine the effectiveness of mathematics project-based learning were measured through classroom observations conducted throughout the fall semester at the school (Appendix E).

Time and effort required from students and teachers was minimal. Approximately 30 minutes was required to complete the surveys at the beginning and end of the semester. Most of the students' participation in the project was accomplished by their regular class attendance and participation. A minimum level of participation and time spent in a PBL setting was expected to be necessary in order for PBL to be an effective instructional method.

Participants

The population of interest was 6th, 7th, and 8th grade students enrolled in mathematics classes in the school system of interest. This particular school system was selected because of their progressive approach to instruction and learning, which leans heavily toward project-based and inquiry-based learning. The sample included all students who returned signed parental permission forms to participate in the study and also completed the online surveys conducted twice throughout the semester, as well as all mathematics teachers in grades 6, 7, and 8 who signed and returned consent forms. All students in grades 6, 7, and 8 were invited to participate. No students were excluded due to educational ability, physical ability, or any other criteria. The school employs one mathematics teacher per grade level for the middle grades, so a total of three teachers were included in the sample. All stamped and approved permission/consent forms and the Institutional Review Board (IRB) approval letter are included in Appendix F.

One limitation of this study is the number of students with matched pre- to post-survey responses. Although responses were collected for both the pre- and post-surveys, few students completed the survey both times. Collecting data from 8th grade students was particularly difficult. The 8th grade classes consistently scored below the other grade levels in terms of PBL implementation, engagement, and classroom culture – these same difficulties made it challenging to obtain survey responses from 8th grade students. While the 6th and 7th grade teachers were able to devote some class time to encouraging students to complete the pre- and post-surveys, the 8th grade teacher was not able to dedicate any class time to survey completion. Classroom management and competing priorities prevented the collection of any 8th grade student survey responses. School enrollment data (retrieved from Alabama State Department of Education) and project participation numbers are presented in the table below.

Table 1: Participant Numbers

	6th	**7th**	**8th**
Total enrollment	151	116	110
Permission forms returned (% of enrollment)	60 (39.7%)	33 (28.4%)	35 (31.8%)
Pre-surveys completed (% of those returning permission forms)	24 (40.0%)	30 (90.9%)	0 (0.0%)
Post-surveys completed (% of those returning permission forms)	44 (73.3%)	5 (15.2%)	0 (0.0%)

Matched pre/post survey responses (% of those returning permission forms)	11 (18.3%)	4 (12.1%)	0 (0.0%)
Global Scholar scores obtained (% of those returning permission forms)	57 (95.0%)	32 (97.0%)	35 (100.0%)
Classroom Performance scores obtained (% of those returning permission forms)	53 (88.3%)	29 (87.8%)	28 (80.0%)

Instrumentation

Student Survey

The primary data collection instrument for obtaining student data was the Attitude Toward Mathematics Inventory (ATMI). Permission has been granted from the authors of the ATMI to use the inventory in this study (M. Tapia, personal communication, January 19, 2017). The ATMI was designed to investigate the underlying dimensions of attitudes toward mathematics, with items constructed to assess confidence, anxiety, value, enjoyment, motivation, and parent/teacher expectations. To estimate internal consistency of the scores, the survey authors calculated the Cronbach alpha coefficient and found it to be .97, indicating a high degree of internal consistency for group analyses. All 40 items had item-to-total correlation above .50, with the highest being .82, suggesting that all items contribute significantly (Tapia & Marsh, 2004). A later study of the ATMI using a confirmatory factor analysis also supported the original four-factor structure (Majeed, Darmawan, & Lynch, 2013).

The table below presents internal consistencies for the pre- and post-ATMI overall survey and the four subscales for this study, calculated using Cronbach's Alpha statistics. The Cronbach's Alpha values ranged from 0.837 to 0.963. This demonstrates a high level of reliability and is in alignment with previous results (Majeed et al., 2013).

Table 2: ATMI Reliability Statistics

	Cronbach's Alpha	**N of Items**
ATMI Overall Score – Pre	.963	40
ATMI Subscale – Self-Confidence – Pre	.946	15
ATMI Subscale – Value – Pre	.837	10
ATMI Subscale – Enjoyment – Pre	.859	10
ATMI Subscale – Motivation – Pre	.880	5
ATMI Overall Score – Post	.951	40
ATMI Subscale – Self-Confidence – Post	.917	15
ATMI Subscale – Value – Post	.840	10
ATMI Subscale – Enjoyment – Post	.883	10
ATMI Subscale – Motivation – Post	.849	5

For the current study, the ATMI was supplemented with survey items developed by the researcher focusing on classroom environment and activities, opportunities to demonstrate mathematical knowledge, and teacher/student interactions (see full supplemental survey in Appendix C). These supplemental items were intended to gauge student opinions about their opportunities to demonstrate their mathematical knowledge, and included questions such as:

- I am able to show my teacher how much I know about math.
- I am able to show my classmates how much I know about math.
- I spend time at home learning about math-related topics.
- When I don’t understand something, my teacher tries to help me by asking questions about my thinking.
- I am able to explain to others how to do math problems.

Internal consistency was also calculated for the pre- and post-supplemental survey items using Cronbach's Alpha and showed high levels of reliability at 0.777 for pre-surveys and 0.815 for post-surveys.

Table 3: Supplemental Survey Items Reliability Statistics

	Cronbach's Alpha	**N of Items**
Supplemental Survey Questions – Pre	.777	20
Supplemental Survey Questions – Post	.815	20

Teacher Survey

Teachers completed a post-semester survey developed by the researcher in which they provided quantitative ratings about their ability to measure students' mathematical abilities through various assessment methods, beliefs and opinions about teaching both pure and applied mathematics, and the opportunities that their students have to express their understanding of mathematical concepts through different kinds of outlets. The sample size for this teacher survey was small (only completed by the three mathematics teachers in grades 6-8 at the school). No complex data analysis was performed with these results, but responses were compared/contrasted with each other and compared to observation data and student survey data within each grade level.

Classroom Observations

For classroom observations, the researcher utilized the STEM Classroom Observation Protocol developed by the SERVE Center at University of North Carolina at Greensboro (Arshavsky et al., 2012). This protocol includes guidelines for assessing 8 areas: mathematics and science content; student cognitive engagement in meaningful instruction; inquiry learning, project-based learning, and problem-based instruction; teacher instruction/formative assessment; common instructional framework; student engagement; use of technology; and classroom culture. This observation protocol assisted in measuring implementation of fidelity of project-based classroom instruction. The protocol allowed for quantitative data to be collected by scoring various aspects of instruction and student engagement on a scale from 0 = not observed to 3 = very descriptive of the observation, and qualitative data was collected by recording notes about specific details of various aspects of the teaching and learning processes. The classroom observation data was used to calculate descriptive statistics, with repeated measures throughout the semester to improve reliability.

Data Collection

At the beginning of the Fall 2016 semester, the Principal Investigator visited the mathematics classrooms of the 6th, 7th, and 8th grades at the school. The research project was explained to all students, and information/consent letters were distributed to students to take home for their parents to sign. The researcher returned to the school the next week to collect the signed forms. No further efforts were made to recruit participants. The link to the online surveys was distributed to students by their classroom teachers using the Edmodo software that is utilized daily for mathematics instruction. The researcher returned to the school four times throughout the Fall 2016 semester to conduct classroom observations. All physical data collection of observations and examination of existing records also took place at the school.

Electronic data was collected through online form surveys developed with Qualtrics software and hosted on a secure server at www.auburn.edu. In addition to obtaining information from individual students, the mathematics classrooms for grades 6-8 were also observed as a whole in order to assess and better understand the project-based instruction methods being implemented. Teachers completed brief surveys at the conclusion of the Fall 2016 semester. Existing data in the form of standardized test scores and classroom performance grades were also collected and examined. Files for approximately 200 students were obtained. These data were provided by a school administrator and merged with data gathered through surveys using student code numbers.

Data Analysis

Several methods were used to conduct data analysis for this study. Teacher and student survey responses were collected using Likert-type scale items. The internal consistencies of the ATMI survey instrument and the supplemental survey questions were calculated using Cronbach's Alpha coefficients. Data analyses of responses included standard inferential statistics and percentages of students improving or increasing from the pre- to the post-survey. Other data analysis techniques used included paired samples t-tests, Pearson correlations, Kendall's coefficient of concordance W, and qualitative analysis of classroom observation data. Data analysis methods by research question are presented below.

Table 4: Data Analysis Methods

Research Question	**Hypothesis**	**Assumptions**	**Statistical Test Performed**	**Test Statistics**
How is project-based mathematics learning currently being implemented and assessed?	Effective project-based mathematics learning instruction and assessment methods are being incorporated in	Middle school mathematics teachers in the school system will implement project-based learning teaching methods in their classrooms.	Descriptive Statistics Qualitative Analysis	Means Standard Deviations

	mathematics classes of the middle grade levels of the school system.	Teachers have received professional development through pre-semester workshops and conferences focusing on project-based learning instructional methods and integrating cross-subject content into their classes.		
How does the school's classroom performance grading system compare to standardized test results?	Students' standardized test scores in mathematics will not have a high correlation with their classroom mathematics grades because of inconsistencies between knowledge measured by test items and the learning outcomes achieved by PBL. A weak positive correlation is expected.	Students in the school system will actively participate in project-based learning instruction and activities. Existing data such as standardized test scores and classroom grades are valid and reliable records that contain accurate student information.	Pearson correlation coefficients	Pearson correlation coefficient, *r* Significance (p-value)

How do student self-assessments relate to grades and scores on standardized tests?	Students' self-assessments (survey responses) and teacher assessments (grades) of their mathematical content knowledge are expected to have a strong positive correlation.	Students in the school system will actively participate in project-based learning instruction and activities. Existing data such as standardized test scores and classroom grades are valid and reliable records that contain accurate student information.	Multiple Regression Backward Elimination Kendall's Coefficient of Concordance, *W*	R Square Standard Error of the Estimate R Square Change F Change Standardized Coefficients Beta Partial Correlations Kendall's *W* Significance (p-value)
Does project-based learning lead to increases in students' levels of self-confidence, value, enjoyment, and motivation in mathematics?	Students' levels of self-confidence, value, enjoyment, and motivation in mathematics will significantly increase after one semester of participation in project-based learning.	Students in the school system will actively participate in project-based learning instruction and activities. PBL teaching methods will be applied with a high level of fidelity of implementation.	Paired Samples T-Tests Descriptive Statistics	t-value Effect Size Means Standard Deviations Change in Means

Chapter IV

Findings

Introduction

Findings show that project-based learning is being implemented at different levels across the middle grades mathematics classes of the school. Some agreement was found between various assessment methods, but no significant increases were found in mathematics self-confidence, value, enjoyment, or motivation. Results are presented below by research question.

RQ1: How is project-based mathematics currently being implemented and assessed?

Implementation

Classroom observations were conducted in mathematics classes of the 6th, 7th, and 8 grades throughout the semester. Four observations took place for each grade level, with each observation consisting of a 55-minute class period. The observations took into account eight areas: mathematics and science content; student cognitive engagement in meaningful instruction; inquiry learning, project-based learning, ad problem-based instruction; teacher instruction/formative assessment; common instructional framework; student engagement; use of technology; and classroom culture. Items for each of these 8 areas were rated on a scale of 0 = not observed, 1 = minimal, 2 = to some extent, and 3 = very descriptive of the observation.

As a whole, project-based learning and problem-based instruction were far more prominent in the 6th and 7th grade classrooms than in the 8th grade classroom. Classroom culture (positive behavior, respectful environment, etc.) was also consistently much better in the 6th and 7th grade classrooms than in the 8th grade classroom. However, asking students to explain or justify their thinking was a common strength across all grade levels. Classrooms at all grade levels still displayed many aspects of traditional instruction, especially in the teacher providing verbal explanations to connect new information to previous knowledge.

Grade 8 had the lowest scores for all nine items in the Project-Based Learning category, all five items in Student Engagement, and all six items in Classroom Culture. Also noteworthy is the fact that at no point during the four classroom observations for 8th grade was technology implemented. This is a stark contrast to the other grade levels, especially 7th grade, where technology was integrated by teachers and used by students almost constantly. The challenges faced in grade 8 account for the lack of student surveys completed by eighth grade students – the teacher simply did not have any spare class time to devote to survey completion, and students were not engaged enough to complete the surveys at home or outside of class. However, in the Math and Science Content category, the 8th grade class had the highest score of the three grade levels in four of the nine items. The 8th grade teacher was particularly skilled in clearly presenting course material and in emphasizing relationships and connections between different skills and concepts. Scales that received the highest scores across all middle grade levels were Mathematics and Science Content, and Teacher Instruction/Formative Assessment. Means and standard deviations from classroom observation scales and individual items are presented in Tables 5 and 6 below.

Table 5: Classroom Observation Data by Grade Level – Scale Scores (Summary of Quality)

Scale	**6th**		**7th**		**8th**	
	M	**SD**	**M**	**SD**	**M**	**SD**
1. Mathematics and Science Content	2.25	1.50	3.00	0.00	2.75	0.50
2. Student Cognitive Engagement in Meaningful Instruction	2.50	0.58	2.00	0.00	1.50	0.58
3. Inquiry Learning; Project-Based Learning; and Problem-Based Instruction	2.50	0.58	2.50	0.58	1.25	0.50
4. Teacher Instruction/Formative Assessment	2.75	0.50	2.75	0.50	3.00	0.00
5. Common Instructional Framework	2.50	0.58	2.75	0.50	2.00	0.82
6. Student Engagement	3.00	0.00	3.00	0.00	1.25	0.50
7. Use of Technology	1.75	0.96	2.50	0.58	0.00	0.00
8. Classroom Culture	3.00	0.00	3.00	0.00	1.50	0.58

Table 6: Classroom Observation Data by Grade Level – Item Scores

	6th		**7th**		**8th**	
	M	**SD**	**M**	**SD**	**M**	**SD**
1. MATHEMATICS AND SCIENCE CONTENT						
1a. Math and science content information was accurate.	2.25	1.50	3.00	0.00	2.75	0.50
1b. Teacher's presentation or clarification of mathematics or science content knowledge was clear.	1.75	1.26	3.00	0.00	3.00	0.00
1c. Teacher used accurate and appropriate mathematics or science vocabulary.	2.75	0.50	3.00	0.00	3.00	0.00
1d. Teacher/students emphasized meaningful relationships among different facts, skills, and concepts.	2.25	1.50	2.50	0.58	3.00	0.00
1e. Student mistakes or misconceptions were clearly addressed (emphasis on correct content here).	2.25	1.50	2.50	0.58	2.50	0.58
1f. Teacher and students discussed key mathematical or science ideas and concepts in depth.	1.25	0.96	2.25	0.50	1.75	0.96
1g. Teacher connected information to previous knowledge.	2.75	0.50	3.00	0.00	2.25	0.50

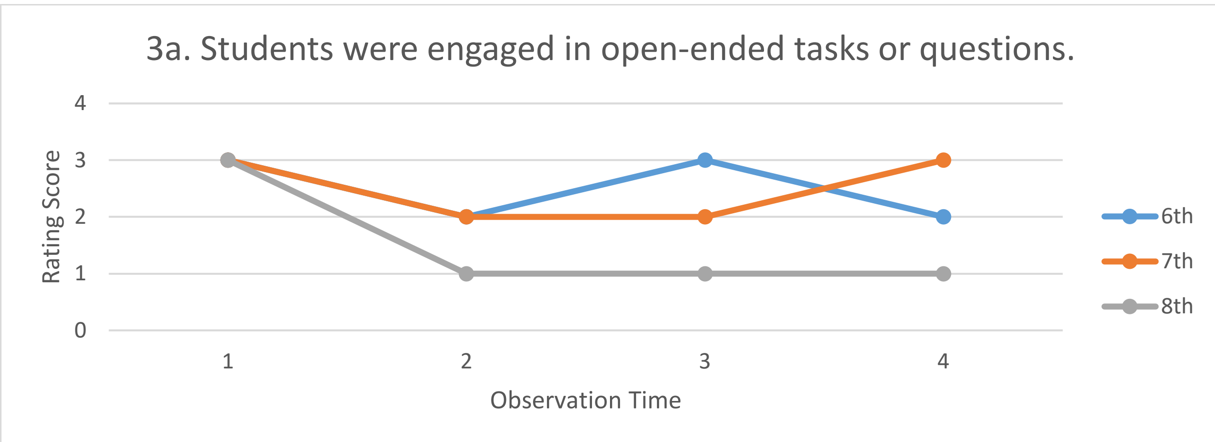
1h. Appropriate connections were made to other areas of mathematics/science or to other disciplines.	0.75	0.50	2.50	1.00	1.00	0.00
1i. Appropriate connections were made to real-world contexts.	1.75	0.96	2.50	1.00	1.00	0.00
2. STUDENT COGNITIVE ENGAGEMENT IN MEANINGFUL INSTRUCTION						
2a. Students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.	2.50	0.58	2.50	0.58	1.75	0.50
2b. Students were asked to explain or justify their thinking.	2.25	0.96	2.50	0.58	2.75	0.50
2c. Students were given opportunities to summarize, synthesize, and generalize.	1.75	0.96	2.00	0.00	1.25	0.50
2d. Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	2.00	0.82	1.50	0.58	1.25	0.50
2e. Students were asked to apply knowledge to a novel situation.	2.50	0.58	2.25	0.50	1.50	0.58
2f. Students were asked to compare/contrast different answers, different solutions, or different explanations/interpretations to a problem or phenomena.	2.75	0.50	2.50	0.58	1.75	0.96
3. INQUIRY LEARNING; PROJECT-BASED LEARNING; AND PROBLEM-BASED INSTRUCTION						
3a. Students were engaged in open-ended tasks or questions.	2.50	0.58	2.50	0.58	1.50	1.00
3b. Students engaged in hands-on or real-life problem solving activities or a lab experiment.	2.00	1.15	2.00	0.82	1.00	0.00
3c. Students developed their own questions and/or hypotheses to explore or test.	1.50	1.00	1.75	0.96	1.25	0.50
3d. Students engaged in scientific inquiry process (tested hypotheses and made inferences).	1.00	0.00	1.50	0.58	1.00	0.00
3e. Students determined which problem solving strategies to use.	3.00	0.00	2.75	0.50	2.00	0.00
3f. Students had to present or explain results of project.	3.00	0.00	3.00	0.00	2.50	0.58
3g. Students worked on a project requiring creativity.	2.75	0.50	2.75	0.50	1.50	1.00

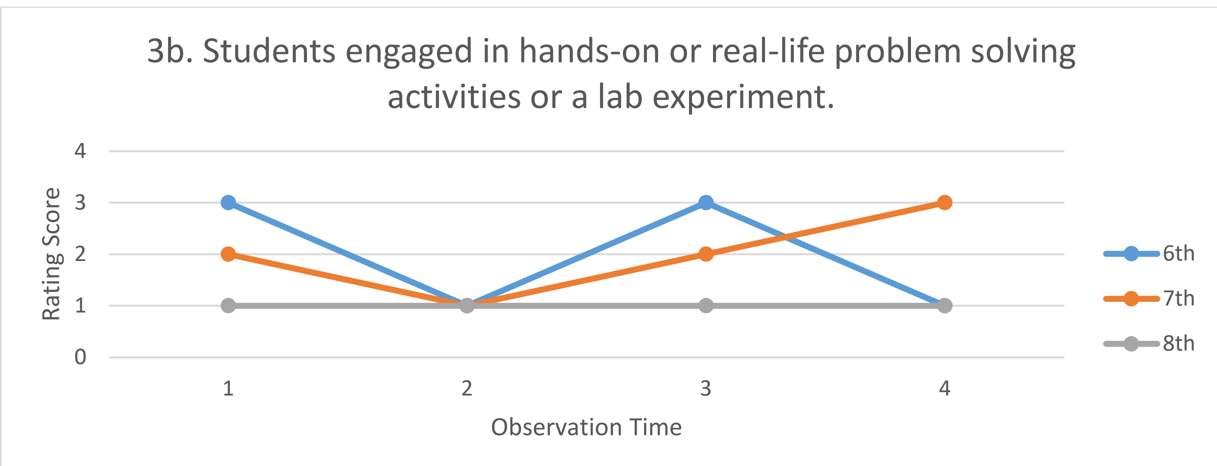
3h. There was an explicit evidence of teacher modeling engineering (or reverse engineering) design process.	2.25	0.50	2.00	0.00	0.75	0.50
3i. There was an explicit evidence of students using engineering (or reverse engineering) design process.	2.25	0.50	2.00	0.00	0.75	0.50
4. TEACHER INSTRUCTION/FORMATIVE ASSESMENT						
4a. Teacher provided clear learning goals to students.	3.00	0.00	3.00	0.00	3.00	0.00
4b. Teacher provided clear criteria for success/examples of good work to students.	2.75	0.50	2.25	0.50	2.50	1.00
4c. Teacher used a variety of strategies to monitor student learning and understanding throughout the lesson.	2.50	0.58	2.00	0.82	2.00	0.00
4d. Teacher provided specific feedback to students.	3.00	0.00	3.00	0.00	2.75	0.50
4e. Students were engaged in self- and/or peer-assessment.	2.50	0.58	2.75	0.50	2.00	0.82
4f. Teacher adjusted or differentiated instruction based on evidence of student learning.	2.50	0.58	2.75	0.50	2.50	0.58
4g. Students were given opportunities to reflect on their own learning.	2.75	0.50	2.75	0.50	2.50	0.58
5. COMMON INSTRUCTIONAL FRAMEWORK						
5a. Students worked collaboratively in teams or groups.	2.00	0.82	2.50	1.00	1.50	1.00
5b. Students used writing to communicate what they had learned.	2.50	0.71	2.00	0.82	2.00	0.82
5c. Teachers asked open-ended questions that required higher level thinking.	2.25	0.50	2.00	0.00	1.50	1.00
5d. Teachers provided assistance/scaffolding when students struggled.	3.00	0.00	3.00	0.00	2.50	0.58
5e. Students engaged in discussion with each other.	2.75	0.50	3.00	0.00	2.25	0.96
5f. Students participated in guided reading discussions.	0.00	0.00	0.00	0.00	0.00	0.00
6. STUDENT ENGAGEMENT						
6a. Students were behaviorally engaged (following directions, on-task behavior, responding to teachers' questions).	3.00	0.00	3.00	0.00	1.00	0.00
6b. The time in class was spent productively on meaningful tasks.	3.00	0.00	3.00	0.00	1.50	0.58
6c. Teacher pursued the active engagement of all students.	2.75	0.50	2.50	0.58	2.00	0.82

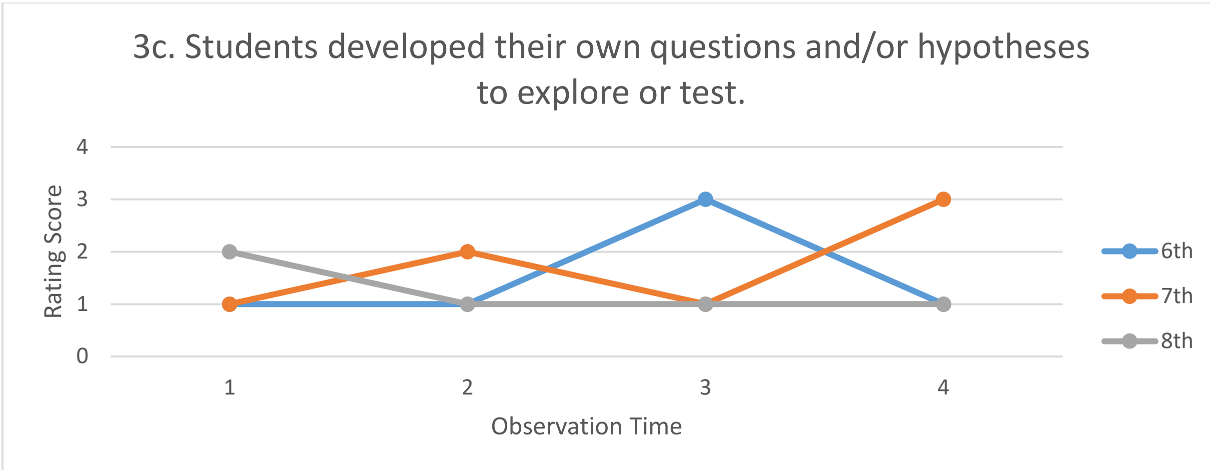
6d. Students appeared cognitively engaged (ask questions of the teacher and each other related to the content and ideas being discussed, follow up on each other's responses, clear evidence of students working/thinking hard on a problem).	3.00	0.00	3.00	0.00	1.75	0.50
6e. Students showed perseverance when solving math/science problems.	2.75	0.50	2.75	0.50	1.25	0.50
7. USE OF TECHNOLOGY						
7a. Technology was used to a high extent (as a proportion of time of the lesson and intensity of use).	1.50	1.29	2.25	0.50	0.00	0.00
7b. Students used technology to explore or confirm relationships, ideas, hypotheses, or develop conceptual understanding.	1.50	1.29	2.25	0.96	0.00	0.00
7c. Students used technology to generate or manipulate one or more representations of a given concept or idea.	1.25	1.26	2.00	0.00	0.00	0.00
7d. Students used technology as a tool to meet a discreet instructional outcome (like an assignment or specific objective).	2.00	1.41	2.75	0.50	0.00	0.00
7e. Students used technology to practice skills or reinforce knowledge.	2.00	1.15	2.50	0.58	0.00	0.00
7f. Technology was used but did not appear to provide any added benefit.	1.25	1.26	1.25	0.96	0.00	0.00
7g. Teacher used technology to achieve instructional goals (emphasis on the "teacher" here).	1.25	0.96	1.25	0.50	0.00	0.00
8. CLASSROOM CULTURE						
8a. Students exhibited positive classroom behavior.	3.00	0.00	3.00	0.00	1.25	0.50
8b. The classroom exhibits a respectful environment.	3.00	0.00	3.00	0.00	1.25	0.50
8c. There is a climate of respect and encouragement for students' ideas, questions, and contributions; mistakes are viewed as an opportunity to learn.	3.00	0.00	3.00	0.00	1.25	0.50
8d. Students and teacher appear to have positive relationships and to enjoy spending time with each other (laughing, easy relationship).	3.00	0.00	2.50	0.58	1.00	0.00
8e. Students actively seek and provide assistance or guidance.	3.00	0.00	3.00	0.00	1.75	0.50
8f. Teachers and students provide positive reinforcement and feedback to each other.	3.00	0.00	2.75	0.50	2.00	0.00

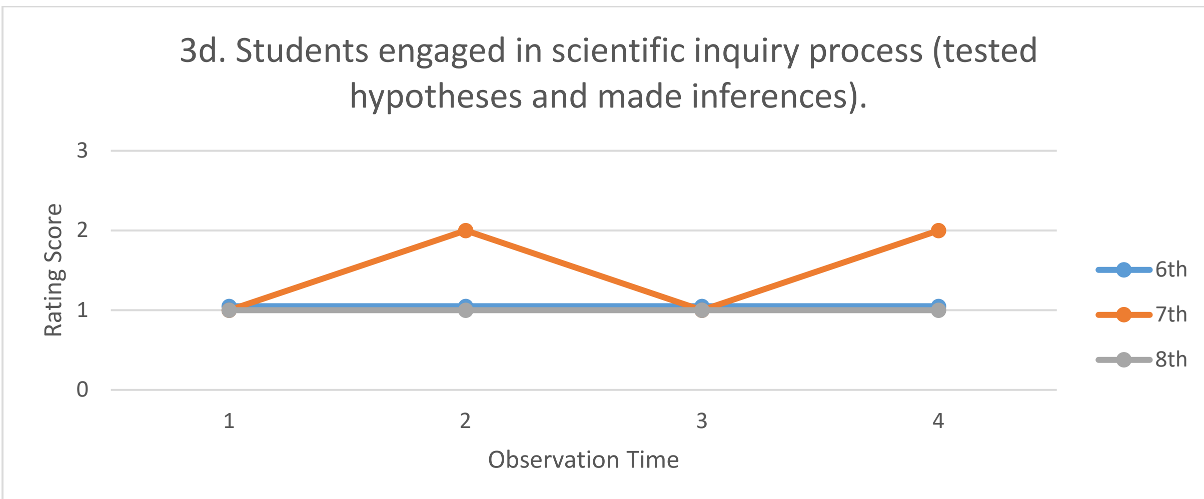
Examining PBL observation scores over the course of the semester shows that grade 7 made the most progress in terms of mathematics PBL implementation. Grade 8 consistently had the lowest scores for all PBL items, and grade 6 tended to remain flat or decrease toward the end of the semester. Grade 7 generally showed upward movement for most PBL areas. Areas with the most room for improvement in the school are incorporating engineering design processes and engaging in the scientific inquiry process. The line graphs below show PBL observation scores by grade level over time.

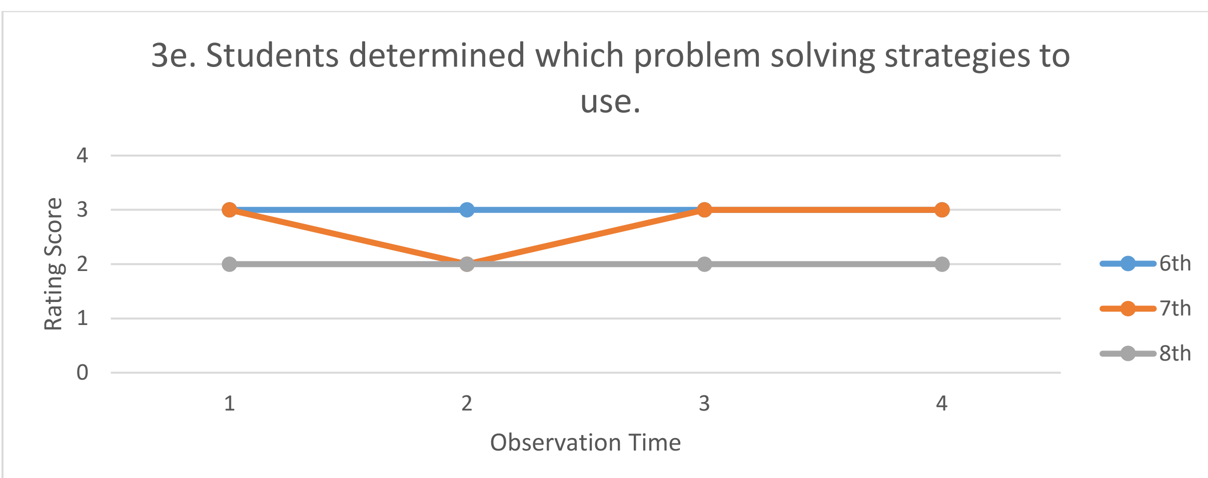
Figure 1: PBL Observation Scores by Grade Level Over Time

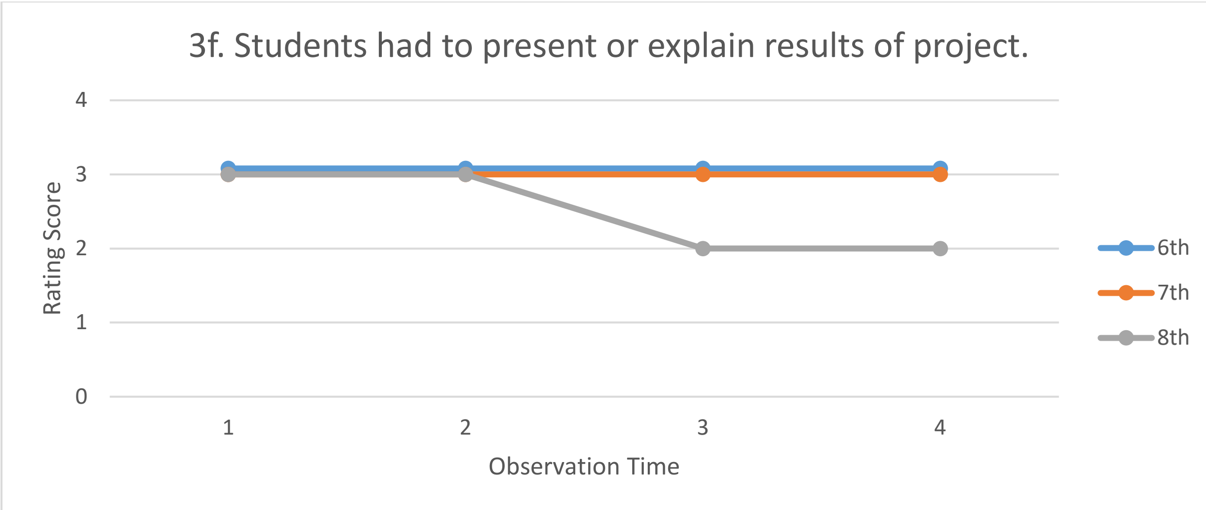


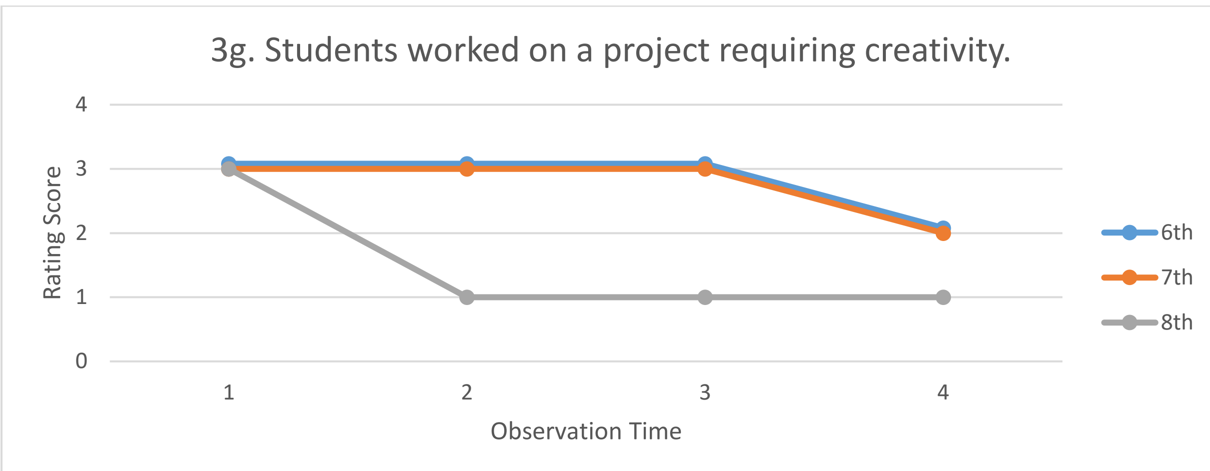


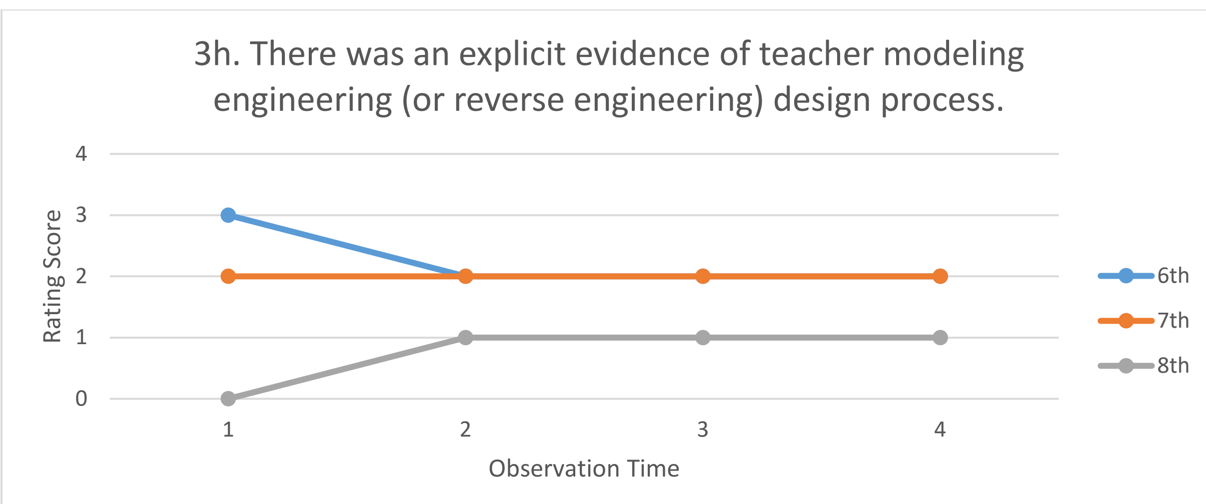

3c. Students developed their own questions and/or hypotheses to explore or test.
Rating Score
0
1
2
3
4
1
2
3
4
Observation Time
6th
7th
8th

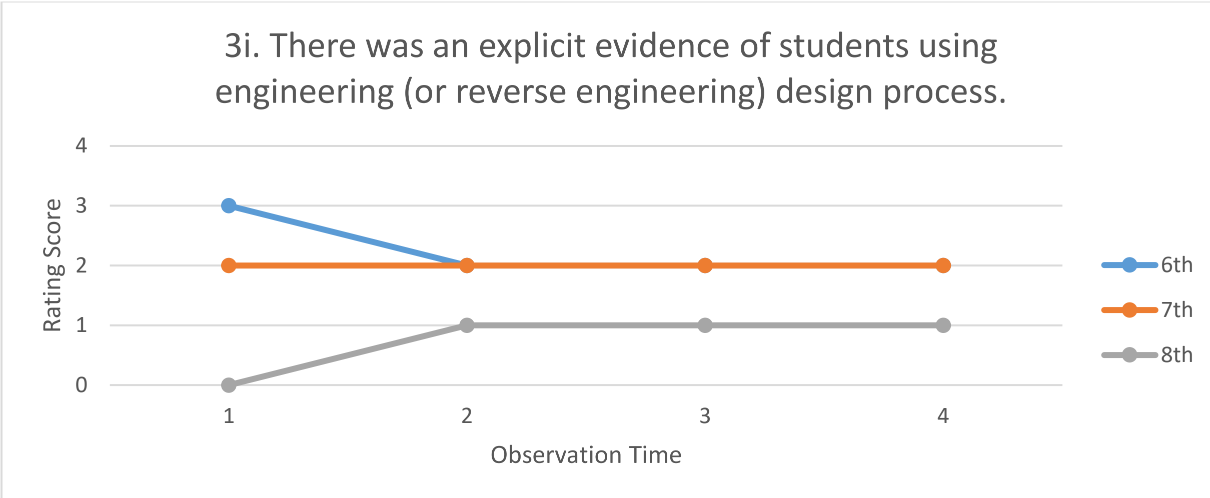

3d. Students engaged in scientific inquiry process (tested hypotheses and made inferences).
Rating Score
0
1
2
3
1
2
3
4
Observation Time
6th
7th
8th

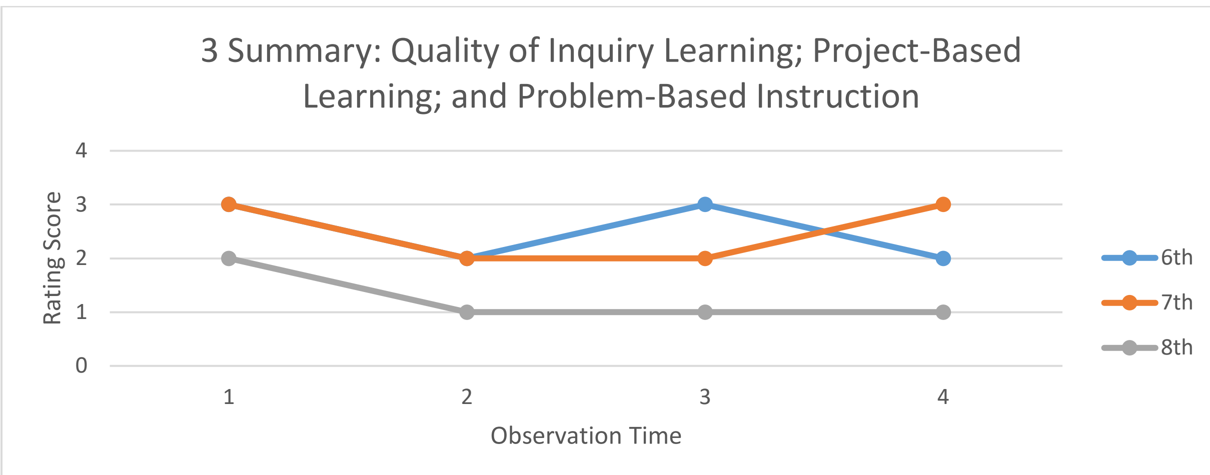

3e. Students determined which problem solving strategies to use.
Rating Score
0
1
2
3
4
1
2
3
4
Observation Time
6th
7th
8th


3f. Students had to present or explain results of project.
Rating Score
4
3
2
1
0
1
2
3
4
Observation Time
6th
7th
8th


3g. Students worked on a project requiring creativity.
Rating Score
4
3
2
1
0
1
2
3
4
Observation Time
6th
7th
8th


3h. There was an explicit evidence of teacher modeling engineering (or reverse engineering) design process.
Rating Score
4
3
2
1
0
1
2
3
4
Observation Time
6th
7th
8th





Referring back to the essential elements of PBL instruction as presented by Krajcik et al., many examples of these elements were seen during the classroom observations that took place throughout the Fall 2016 semester. The school has successfully created an environment where PBL mathematics learning is able to be implemented in the middle grades. The key elements are presented again below, followed by an example of each element that took place during observed mathematics classes.

- Projects engage students in investigating an authentic question or problem.

- 7th grade students researched prices of various items sold in bulk on Amazon, learning about ratios and unit rates.

- Students develop a series of artifacts, or products, that address the question/problem.
  - 6th grade students created videos explaining how to evaluate expressions in which letters stand for numbers. The videos were then shown to members of a lower-level math class, with the 6th graders serving as peer leaders.
- Students, teachers, and members of society are involved in a community of inquiry and collaboration.
  - 8th grade students worked in groups to solve problems involving rules of exponents. Students collaborated to write out meaningful questions to be asked after presentations by other groups.

Assessment

Summative student assessment in mathematics took place using two methods: a classroom performance rating assigned by the teacher, and a Global Scholar Performance Series standardized test score. Classroom performance was rated by the mathematics teacher at the end of each nine weeks, and students were assigned a rating on the following five-point scale.

Classroom Performance Assessment Ratings:

NME = Not Meeting Expectation of grade level understanding.

AAE = Almost Approaching Expectation of grade level understanding.

AE = Approaching Expectation of grade level understanding.

AME = Almost Meeting Expectation of grade level understanding.

MLE = Meeting Learning Expectation of grade level understanding.

The rating received by the student is dependent upon their performance during the previous nine weeks of school. The teacher considers multiple factors when assigning student ratings, including individual projects and assignments, small group projects, class-wide projects, and the student's portfolio of work for the term uploaded to the FreshGrade portfolio and assessment platform. The portfolio can include evidence of learning such as completion certificates from online mathematics exercises, pictures of objects and projects the student has created, and electronic products such as videos, pictures, audio clips, notes, and presentations (FreshGrade, n.d.).

Classroom performance ratings by grade level are presented below for each of the first three nine-week periods. Distributions reveal that arbitrary decisions by teachers may lead to discrepancies in classroom performance scores across grade levels. Although students in both the 6th and 7th grades performed well on mathematics standardized tests and outscored the national means for their respective grade levels (see Table 8 below), a majority of 6th grade students received scores of MLE = Meeting Learning Expectation, but a majority of 7th grade students consistently received scores of AME = Almost Meeting Expectation. This suggests that teachers may have a "default" score in mind as a starting point for evaluating each student. MLE ratings were very rare among 7th grade students, although they did not differ significantly from 6th grade students according to other assessment methods. Students in 8th grade received more evenly distributed scores between AE, AME, and MLE scores. NME and AAE, the lowest two ratings, were rarely given in any grade level. Classroom performance scores were seen to decrease over time in grades 6 and 8, with the percentage of students receiving MLE decreasing each nine-weeks in those two grade levels.

Table 7: Classroom Performance Scores by Grade Level

Grade Level	**6th**			**7th**			**8th**		
Nine-Weeks Period	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
NME	0 (0.0%)	2 (3.8%)	2 (3.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (7.1%)	0 (0.0%)
AAE	2 (3.8%)	1 (1.9%)	1 (1.9%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (7.1%)	3 (10.7%)
AE	4 (7.7%)	5 (9.4%)	11 (21.2%)	6 (20.7%)	8 (27.6%)	8 (27.6%)	6 (25.0%)	9 (32.1%)	10 (35.7%)
AME	12 (23.1%)	14 (26.4%)	13 (25.0%)	22 (75.9%)	21 (72.4%)	16 (55.2%)	7 (29.2%)	7 (25.0%)	10 (35.7%)
MLE	34 (65.4%)	31 (58.5%)	25 (48.1%)	1 (3.4%)	0 (0.0%)	5 (17.2%)	11 (45.8%)	8 (28.6%)	5 (17.9%)

The standardized testing system utilized by the school is the Global Scholar Performance Series. The tests are computer adaptive, multiple choice assessments with questions that adapt to each individual student's instructional level based on the Rasch Model of measurement in Item Response Theory (IRT). The calculated scaled score is independent of grade level and uses a single parameter, item difficulty, to estimate an individual's proficiency level based on responses (Scantron, 2017). The tests are aligned to the College and Career Readiness Standards in the Alabama Course of study for ELA and Math, as well as ACT Quality Core standards in grades K-12. The Performance Series has been utilized by districts across the state of Alabama since school year 2011-2012 (Alabama State Department of Education, 2018).

The test produces a scaled mathematics score for each student that ranges from 1300 to 3700. Mean mathematics scaled scores for participants from the third nine-weeks period of the 2016-2017 school year are presented below, along with mean mathematics scaled scores for the nation (Scantron, 2017). For grades 6 and 7, sampled students within the system have mean mathematics scaled scores higher than the national average. Student scores among participants also increased on average from 6th grade to 7th grade. As noted earlier, possible scores range from 1300 to 3700 and are independent of grade level – therefore, one would expect to see an increase in mean scores as grade level increases. However, for grade 8, sampled students within the system have mean mathematics scaled scores lower than the national average, and also lower than the 7th grade students in the system. This is consistent with the lower levels of project-based learning implementation, student engagement, technology integration, and classroom culture in the 8th grade.

Table 8: Global Scholar Mathematics Mean Scaled Scores

	6th	**7th**	**8th**
Participants	2624	2744	2663
Nation	2580	2655	2715

Teacher Surveys

The three mathematics teachers at the school completed a short survey at the conclusion of the Fall 2016 semester. This survey asked them to provide their opinions about the extent to which they are able to measure student learning through various assessment methods, the importance of teaching both practical, real world applications of mathematics and the theoretical, pure mathematics behind those applications, and the availability of various outlets for students to express their understanding of mathematical concepts. The full survey is presented in Appendix D. The teachers rated individual projects or assignments as more valuable for assessment purposes than small group projects or class-wide projects. They rated both practical applications and pure mathematics as being important to teach students, but placed more importance on the practical applications. Departing from traditional assessment methods, the teachers indicated that their students have more opportunities to express their understanding of mathematics verbally than through writing. Teachers indicated a lack of opportunities for students to express mathematical understanding through creative outlets such as visual, musical, or other performing arts. Observation notes also show more opportunities for students to demonstrate their knowledge through vocal expressions than through written expressions, and observation data confirms a lack of opportunities for students to utilize creative expression outlets. Means and standard deviations for each survey item are presented below.

Table 9: Teacher Survey Item Statistics

Teacher Survey Item	**Valid N**	**M**	**SD**
1. I am able to determine my students' mathematical abilities based on their contributions to class-wide projects.	3	4.00	1.000
2. I am able to determine my students' mathematical abilities based on their contributions to small group projects.	3	4.67	.577
3. I am able to determine my students' mathematical abilities based on individual projects or assignments.	3	5.00	.000
4. It is important to teach students how to solve math problems through practical, real world applications.	3	5.00	.000
5. It is important to teach students the theoretical, pure mathematics behind the processes they are learning.	3	4.33	.577
6. Students in my class have opportunities to vocally express their understanding of mathematical concepts.	3	4.33	.577
7. Students in my class have opportunities to express their understanding of mathematical concepts through writing.	3	3.33	.577
8. Students in my class have opportunities to express their understanding of mathematical concepts through creative outlets in visual, musical, or other performing arts.	3	2.67	1.155

Overall, the school is successfully using a variety of assessment methods to measure students' mathematical knowledge and learning. The system is doing well in terms of assessment by utilizing individual portfolios and weighted scoring (Piper, 2012). More should be done in the area of role-based assessment. None of the observed class periods in any grade level utilized a cycling of lead and supporting roles for students. Students were given many opportunities to create artifacts and contribute to group work, but the roles of group leaders and support members were always arrived upon by the students as a function of their personalities, abilities, etc. Teachers could be more deliberate in ensuring that these roles vary and grading students on their supporting actions as well as final products.

RQ2a: How does the school's classroom performance grading system compare to standardized test results?

Pearson Correlation Coefficients

Pearson correlation coefficients were calculated to examine agreement between classroom performance grades and Global Scholar scaled scores for each of the first three grading periods during the 2016-2017 school year. In each grading period, classroom performance grades and Global Scholar scaled scores were found to have significant correlation, $p < .01$. Although correlations were not strong, the Pearson correlation coefficients did increase each nine weeks, suggesting that teachers' classroom performance ratings of students may have become more accurate over the course of the semester. Distributions of classroom grades as presented in Table 7 do show changes over time in the proportions of students at each ranking. In the 6^{th} and 8^{th} grades, there was a marked decline in the percentage of students receiving the highest ranking, Meets Learning Expectations, over the course of the year. Overall, the significant correlations between classroom grades and standardized test scores indicate that teachers are able to successfully evaluate students' learning and levels of mastery.

Table 10: Correlations between Classroom Performance Ratings and Global Scholar Scaled Scores

	N	Pearson Correlation Coefficient	Sig. (2-tailed)
Grading Period 1	104	r = .342	p < .01
Grading Period 2	108	r = .366	p < .01
Grading Period 3	108	r = .486	p < .01

RQ2b: How do student self-assessments relate to grades and scores on standardized tests?

Pearson Correlation Coefficients

Pearson correlation coefficients were calculated to examine agreement between classroom performance grades from the third nine-weeks grading period of the school year and post-ATMI self-assessment scores. The third nine-weeks grading period was used for comparison because this grading period occurred at the closest point in time to the collection of post-ATMI survey responses. No statistically significant correlations were found between classroom performance ratings and any ATMI subscale or ATMI overall score.

Table 11: Correlations between Classroom Performance Ratings and ATMI Post Scores

	N	Pearson Correlation Coefficient	Sig. (2-tailed)
Self-Confidence	44	r = .229	.135
Value	44	r = .147	.340
Enjoyment	44	r = .037	.813
Motivation	44	r = .151	.326
Overall Score	44	r = .175	.257

Multiple Stepwise Regression

A multiple stepwise regression was run to predict Global Scholar Scaled Score from the post-ATMI subscale scores. The final model retained only self-confidence as a predictor. Value, enjoyment, and motivation were not retained as predictors. Regression findings are presented in Tables 12 and 13 below.

Table 12: Regression Findings – ATMI Scores and Global Scholar Scores

Factor	**R^2**	**S.E. Estimate**	**r**	**Semi-partial**	**Standardized Coefficients Beta**
Full Model	.200[a]	169.024			
Self Confidence			.350	.363	.577*
Value			.109	.010	.013
Enjoyment			.069	-.263	-.465
Motivation			.207	.073	.139
Final Model	.123[b]	170.867			
Self-Confidence			.350	.350	.350*

* $p < .05$

[a] $F(4, 41) = 2.564, p = .052$

[b] $F(1, 44) = 6.156, p = .017$

Table 13: R Square Change Test Findings

R^2 Full Model	**R^2 Final Model**	**R^2 Change**	**F Change**	**Sig. F Change**
.200	.123	-.077	1.322	.280

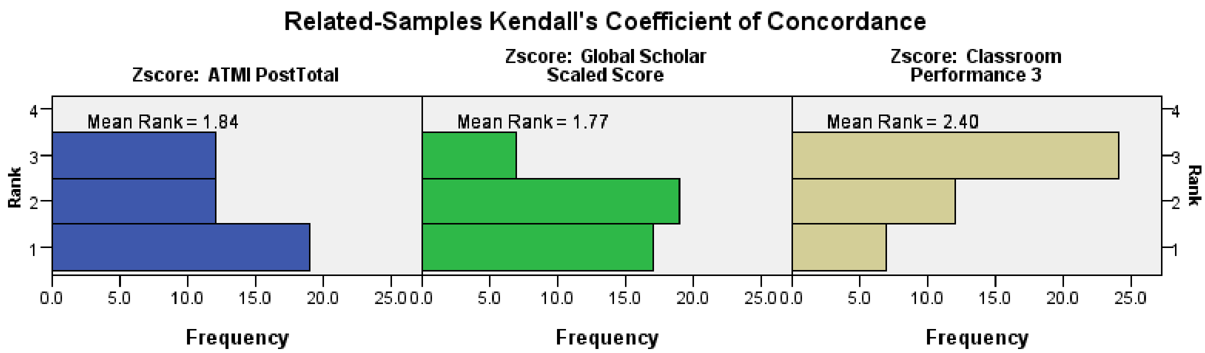
Kendall's Coefficient of Concordance *W*

As a measure of overall agreement between the various assessment methods being considered, namely ATMI total scores, Global Scholar scaled scores, and classroom performance ratings, a Kendall's coefficient of concordance *W* statistic was calculated (Kendall & Smith, 1939). This measure of inter-rater agreement was applied to the assessment data by considering each assessment method as an independent judge. Because of the varying scales for each method, all scores were standardized prior to calculating the Kendall's *W*. The three assessment methods do statistically significantly agree, $W = 0.118$, $p < .05$. However, the relatively low value of Kendall's W suggests only weak agreement.

Table 14: Kendall's Coefficient of Concordance Hypothesis Test Summary

Hypothesis Test Summary				
	Null Hypothesis	**Test**	**Sig.**	**Decision**
1	The distributions of Zscore: ATMI PostTotal, Zscore: Global Scholar Scaled Score and Zscore: Classroom Performance 3 are the same.	Related-Samples Kendall's Coefficient of Concordance	.006	Reject the null hypothesis.
Asymptotic significances are displayed. The significance level is .05.				

Figure 2: Kendall’s Coefficient of Concordance Results



Total N	43
Kendall's W	.118
Test Statistic	10.186
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.006

RQ3: Does project-based learning lead to increases in students’ levels of self-confidence, value, enjoyment, and motivation in mathematics?

ATMI Paired Samples

Paired samples t-tests were conducted to determine whether or not any statistically significant increases occurred between the pre-survey and post-survey in the areas of self-confidence, value, enjoyment, and motivation in mathematics, as well as ATMI overall scores. The sample size for the paired samples test was small, with only N = 15 students completing both the pre- and post-surveys. Neither the overall scores nor any of the subscales were found to have a statistically significant change. Mean scores among the 15 paired students did slightly increase in the areas of value and enjoyment. Mean scores slightly decreased in the areas of self-confidence and motivation, as well as ATMI total scores. Cohen's d statistics show small effect sizes for all subscales and overall scores.

Table 15: Summary of ATMI Paired T-Tests

	N	**Pre**	**Post**	**Change**	**t**	**Effect Size**
		Mean (SD)	**Mean (SD)**	**Mean (SD)**		
Self-Confidence	15	57.47 (12.21)	56.47 (11.55)	-1.00 (6.536)	-.593	-.153
Value	15	40.13 (5.87)	41.00 (6.40)	.87 (4.824)	.696	.180
Enjoyment	15	35.07 (7.87)	35.53 (7.26)	.46 (4.998)	.362	.092
Motivation	15	17.93 (4.67)	17.27 (4.73)	-.66 (2.769)	-.933	-.238
Overall Score	15	150.60 (26.44)	150.27 (25.73)	-.33 (13.393)	-.096	-.025

Supplemental Survey Items Paired Samples

A paired samples t-test was also conducted to determine whether or not a statistically significant increase occurred between the pre-survey and post-survey for the Supplemental Survey Items overall scores. The sample size for the paired samples test was small, with only N = 15 students completing both the pre- and post-surveys. The scores were not found to have a statistically significant change. Mean scores among the 15 paired students slightly decreased, from 66.00 to 65.93. Cohen's d statistics shows a very small effect size.

Table 16: Summary of Supplemental Survey Items Paired T-Test

	N	**Pre**	**Post**	**Change**	**t**	**Effect Size**
		Mean (SD)	**Mean (SD)**	**Mean (SD)**		
Overall Score	15	66.00 (11.30)	65.93 (10.30)	-.07 (4.20)	-.061	-.025

ATMI Independent Samples

Due to the small sample sizes for the paired samples t-test, independent samples t-tests were also conducted to compare ATMI pre- and post-survey responses. Results were consistent with the paired samples t-tests in that no statistically significant changes were found. Among all respondents regardless of matching, mean scores increased slightly for all four ATMI subscale areas and for ATMI total scores. Results are presented in Tables 17 and 18 below.

Table 17: ATMI Independent Samples T-Tests Group Statistics

	Test	**N**	**Mean**	**SD**	**Std. Error Mean**
Self-Confidence	Pre	53	56.02	13.044	1.792
	Post	49	56.06	11.497	1.642
Value	Pre	53	39.87	5.851	.804
	Post	49	40.41	5.975	.854
Enjoyment	Pre	53	35.53	8.004	1.099
	Post	49	36.00	8.150	1.164
Motivation	Pre	53	16.60	5.168	.710
	Post	49	16.82	4.676	.668
ATMI Total	Pre	53	148.02	28.763	3.951
	Post	49	149.29	25.802	3.686

Table 18: Summary of ATMI Independent Samples T-Tests

	t	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
						Lower	**Upper**
Self-Confidence	-.017	100	.986	-.042	2.443	-4.889	4.804
Value	-.461	100	.646	-.540	1.171	-2.864	1.784
Enjoyment	-.295	100	.769	-.472	1.600	-3.646	2.703
Motivation	-.217	100	.828	-.213	.979	-2.154	1.729
Overall Score	-.233	100	.816	-1.267	5.427	-12.033	9.499

Pre- and Post- Item Statistics

ATMI

The table below presents the pre- and post- N, mean score, standard deviation, and pre-post difference for each item of the ATMI. This is not a matched sample – all survey responses are included in this data. All ATMI items used a 5-point scale of 1 = Strongly Disagree to 5 = Strongly Agree. The items showing the largest increases from pre- to post- were representative of all four subscales of the ATMI. The following items had the largest increases in mean value:

- Math is one of the most important subjects for people to study. (Value subscale, +0.40)
- Math is important in everyday life. (Value subscale, +0.37)
- I am happier in math class than in any other class. (Enjoyment subscale, +0.35)
- I really like math. (Enjoyment subscale, +0.29)
- I would like to avoid using math in high school. (Reverse-scored, Motivation subscale, +0.25)
- Math is one of my most dreaded subjects. (Reverse-scored, Self-confidence subscale, +0.24)

Table 19: ATMI Survey Item Statistics

ATMI Survey Item	PRE			POST			PRE-POST DIFF.
	N	Mean	SD	N	Mean	SD	
SELF-CONFIDENCE							
9. Math is one of my most dreaded subjects.*	58	3.47	1.26	57	3.70	1.38	0.24
19. I expect to do fairly well in any math class I take.	58	3.81	1.00	57	3.93	0.98	0.12
22. I learn math easily.	54	3.52	1.08	50	3.62	1.12	0.10
14. When I hear the word math, I have a feeling of dislike.*	58	3.76	1.38	57	3.84	1.21	0.08
15. It makes me nervous to even think about doing a math problem.*	58	4.05	1.13	57	4.09	1.01	0.04
16. Math does not scare me at all.	58	3.71	1.20	57	3.70	1.18	-0.01

21. I feel a sense of insecurity when attempting math.*	54	3.80	1.09	50	3.78	1.00	-0.02
40. I believe I am good at solving math problems.	54	3.78	1.14	49	3.73	1.15	-0.04
13. I am always under a terrible strain in math class.*	58	3.83	1.14	57	3.75	1.12	-0.07
12. Math makes me feel uncomfortable.*	58	4.05	1.07	57	3.88	1.10	-0.17
17. I have a lot of self-confidence when it comes to math.	58	3.45	1.08	57	3.26	1.26	-0.19
20. I am always confused in my math class.*	58	3.88	1.11	57	3.68	1.20	-0.20
10. My mind goes blank and I can't think clearly when doing math.*	58	3.64	1.24	57	3.42	1.15	-0.22
11. Studying math makes me feel nervous.*	58	3.74	1.18	57	3.51	1.20	-0.23
18. I am able to solve math problems without too much trouble.	58	3.55	1.13	57	3.30	1.31	-0.25
VALUE							
6. Math is one of the most important subjects for people to study.	58	3.62	0.93	57	4.02	1.09	0.40
5. Math is important in everyday life.	58	3.98	1.03	57	4.35	0.83	0.37
7. High school math classes would be very helpful no matter what kind of job I want.	58	3.72	1.04	57	3.84	0.98	0.12
8. I can think of many ways that I use math outside of school.	58	3.69	1.08	57	3.79	1.08	0.10
35. I think studying advanced math is useful.	54	3.83	0.97	49	3.92	1.02	0.09
36. I believe studying math will help me with other kinds of problem solving.	54	3.98	0.86	49	4.04	0.93	0.06
2. I want to improve my math skills.	58	4.31	0.71	57	4.37	0.64	0.06
1. Math is an important and necessary subject.	58	4.41	0.73	57	4.39	0.77	-0.03
39. A strong math background can help me later in my job.	54	4.15	0.92	49	4.10	0.96	-0.05
4. Math helps develop the mind and teaches a person to think.	58	4.05	0.80	57	3.72	1.01	-0.33
ENJOYMENT							
30. I am happier in math class than in any other class.	54	2.83	1.30	49	3.18	1.20	0.35
29. I really like math.	54	3.43	1.31	49	3.71	1.24	0.29
27. I would rather do a math assignment than write an essay.	54	3.85	1.42	49	4.02	1.39	0.17
31. Math is a very interesting subject.	54	3.48	1.13	49	3.63	1.11	0.15
24. I have usually enjoyed doing math in school.	54	3.56	1.28	49	3.67	1.09	0.12
25. Math is dull and boring.*	54	3.76	1.18	49	3.76	1.09	0.00
37. I feel comfortable expressing my own ideas about how to solve a difficult math problem.	54	3.24	1.29	49	3.22	1.21	-0.02
26. I like to solve new problems in math.	54	3.67	1.10	49	3.63	1.11	-0.03
38. I feel comfortable answering questions in math class.	54	3.61	1.05	49	3.35	1.16	-0.26
3. I feel good when I solve a math problem.	58	4.16	0.87	57	3.82	0.98	-0.33

MOTIVATION							
28. I would like to avoid using math in high school.*	54	3.67	1.29	49	3.92	1.10	0.25
32. I am willing to take more math classes than I have to.	54	3.13	1.23	49	3.24	1.16	0.12
34. I like the challenge of doing math.	54	3.43	1.28	49	3.51	1.19	0.08
33. I want to take as many math classes as I can in school.	54	2.87	1.23	49	2.73	1.20	-0.14
23. I think I could learn advanced math.	54	3.59	1.24	49	3.41	1.26	-0.18

* Items were reverse-scored.

Supplemental Survey Items

The table below presents the pre- and post- N, mean score, standard deviation, and pre-post difference for each supplemental survey item. This is not a matched sample – all survey responses are included in this data. All supplemental survey items used a 5-point scale of 1 = Strongly Disagree to 5 = Strongly Agree. The largest increases were for items related to practicing things repetitively during math class, needing extra help in math class, and thinking about different ways to solve math problems.

Table 20: Supplemental Survey Item Statistics

Supplemental Survey Item	**PRE**			**POST**			**PRE-POST DIFF.**
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	
44. In math class, we practice things over and over until we get them right.*	51	2.25	1.00	48	2.50	1.03	0.25
58. I feel like I need extra help to stay caught up in math class.*	51	3.16	1.38	48	3.40	1.27	0.24
53. My teacher asks us to think about different ways to solve each math problem.	51	3.25	0.91	48	3.46	1.11	0.20
54. I am able to show my teacher how much I know about math.	51	3.61	1.17	48	3.75	1.04	0.14
46. My teacher tries to understand my way of doing math problems.	51	3.14	1.17	48	3.23	1.04	0.09
60. I am able to explain to others how to do math problems.	51	3.37	1.09	48	3.44	1.07	0.06
My teacher asks me to show my work with pictures.	51	2.33	1.13	48	2.38	1.18	0.04
49. In math class, we work on one big math problem for a long time.	51	2.41	0.98	48	2.42	0.94	0.00

59. I am able to learn how to do math problems presented during class.	51	3.82	0.95	48	3.79	1.01	-0.03
50. My teacher shows us how to solve math problems, and then we practice similar problems.	51	4.24	0.79	48	4.19	0.84	-0.05
51. My teacher is interested in my work even if it is wrong.	51	3.47	1.03	48	3.42	1.18	-0.05
52. When I don't understand something, my teacher tries to help me by asking questions about my thinking.	51	3.35	1.15	48	3.29	1.37	-0.06
45. I work on math problems during class time with other students in my class.	51	3.61	0.98	48	3.54	0.99	-0.07
43. My teacher asks me to explain how I got my answers to math problems.	51	3.82	1.07	48	3.73	0.98	-0.09
55. I am able to show my classmates how much I know about math.	50	3.58	1.18	48	3.44	1.15	-0.14
48. We do projects that are graded.	51	3.55	1.15	48	3.38	1.35	-0.17
41. I like to come up with new ways to solve math problems.	51	3.45	1.15	48	3.27	1.14	-0.18
42. I believe that there is usually one right way to solve math problems.*	51	3.53	1.29	48	3.33	1.19	-0.20
57. I spend time at home learning about math-related topics.	51	2.86	1.31	48	2.63	1.16	-0.24
56. I spend time at home doing math on my own.	51	2.98	1.21	48	2.58	1.07	-0.40

* Items were reverse-scored.

Conclusion

Classroom observations demonstrate that project-based learning is being implemented at varying levels across the middle grades of the school system at the center of this study, more so in the sixth and seventh grade classrooms than in eighth grade. Students in eighth grade classes were consistently not engaged and scored lower than other grade levels in all PBL areas. Specific areas of project-based learning instruction that received high scores for the sixth and seventh grades were: students were engaged in open-ended tasks or questions; students determined which problem solving strategies to use; students had to present or explain results of a project; and students worked on a project requiring creativity. In addition to creative projects and open-ended questions, all mathematics classrooms also utilized traditional lecture-style instruction approaches. Each teacher provided clear learning goals to students, and there was no evidence of long-term (lasting all semester or all year) mathematical projects or activities.

Formal assessment measures including Global Scholar standardized test scores and classroom performance ratings determined by teachers did significantly correlate with each other for each grading period, but a Kendall's Coefficient of Concordance *W* indicated only weak levels of agreement. Self-confidence was identified as a subscale of the ATMI that significantly predicted Global Scholar scaled scores.

Statistically significant improvement was not seen over the course of the study in any subscale of the ATMI or in ATMI total scores, but limitations include a small matched sample size and the short time frame of the study, covering only one semester. Also, the stability of motivation scores over the course of the semester can be viewed as a positive result, since motivation in mathematics is known to typically decrease over time during the middle grades years (Pajares & Graham, 1999).

Chapter V

Discussion

Summary of Findings

Classroom observations demonstrated that project-based learning and assessment looks different across the middle grade levels of the school system under consideration. Over the course of one semester, project-based learning scores obtained through classroom observations did not have noticeable trends in any direction, but rather remained stable throughout the study. Aspects of PBL that were most evident included students being engaged in open-ended tasks or questions; students determining which problem-solving strategies to use; students presenting or explaining results of a project; and students working on a project requiring creativity. In addition to creative projects and open-ended questions, all mathematics classrooms also applied many components of traditional instruction. New material was most often introduced to students by teacher-given lectures and demonstrations. The individual and group assignments were usually short-term projects that could be completed in either one class period or a few class periods. Long-term projects spanning the semester or the academic year were not observed.

Formal assessment measures including Global Scholar standardized test scores and classroom performance ratings determined by teachers were found to have statistically significant correlations. Calculating a Kendall's Coefficient of Concordance W indicated only weak levels of agreement between the various assessment methods employed in the school's mathematics classrooms. Self-confidence was identified as a subscale of the ATMI that significantly predicted Global Scholar scaled scores, while no other ATMI subscales significantly contributed to the regression model. No ATMI subscales correlated significantly with classroom performance scores. Classroom performance and Global Scholar scores did have statistically significant correlation.

Discussion

PBL literature provides many standards and goals that school systems should strive for when implementing and assessing mathematics PBL instruction. This school system is doing many things in a manner that is consistent with a high level of fidelity of implementation to a PBL approach. Strengths of the system include providing students with opportunities to verbally explain or justify their thinking; allowing students to work collaboratively in teams and groups; and teachers providing accurate and thorough content information to students.

The three mathematics teachers in the three grade levels considered in this study all approached instruction and assessment with a project-based mindset and orientation. However, the actual instruction methods used in mathematics classes differed among grade levels, with more traditional methods being implemented in the older grades. While some of these differences may be accounted for by the varying difficulty of material (mathematics concepts in earlier grades lending themselves more easily to project-based learning and assessment), differences in student behaviors and teachers' backgrounds and levels of experience may also affect the extent of PBL instruction and assessment that takes place in mathematics classes.

Important areas where the system fell short in implementing and assessing mathematics PBL include: making more connections to real-world contexts; discussing key mathematical concepts in depth; engaging students in the scientific inquiry process; providing opportunities for students to engage in problem solving activities and/or experiments; and utilizing role-based assessments.

One surprising finding in this study was that no statistically significant improvement was seen over the course of the study in any subscale of the ATMI or in ATMI total scores. The subscale areas considered were self-confidence, value, enjoyment, and motivation in mathematics. Limitations and possible explanations for the lack of improvement in these areas include a small matched sample size and the short time frame of the study, covering only one semester.

Suggestions for Future Research

With regard to project-based learning, less research exists on the effectiveness of PBL in mathematics classes as compared to science classes such as biology and physics. Of particular interest regarding mathematics project-based learning is how the effectiveness of such instruction can be accurately measured, benefits of a project-based approach over a traditional approach, and other classroom factors that affect the impact of mathematics project-based learning.

This study would have been strengthened a great deal by a larger number of matched students responding to both the pre- and post-surveys and by examining project-based mathematics learning implementation and assessment over multiple semesters or multiple academic years. Future research should address the generalizability of this study’s findings to other grade levels and other subject areas. Future research should also consider the effect of demographic factors and other possible confounding variables on project-based learning outcomes. Demographic information for participants (other than grade level) was not attainable for this study.

Hypotheses and Conclusions

- Hypothesis: Effective project-based mathematics learning instruction and assessment methods are being incorporated in mathematics classes of the middle grade levels of the school system.

  Conclusion: Effective PBL instruction and assessment methods are indeed being incorporated in the school's 6^{th}, 7^{th}, and 8^{th} grades' mathematics classes, although at differing levels of implementation.

- Hypothesis: Students' standardized test scores in mathematics will <u>not</u> have a strong correlation with their classroom mathematics grades because of inconsistencies between knowledge measured by test items and the learning outcomes achieved by PBL. A weak positive correlation is expected.

  Conclusion: This hypothesis was supported. Standardized test scores from the Global Scholar scaled scores and classroom performance ratings assigned by teachers did in fact have a weak to moderate positive correlation, which was statistically significant. No significant correlations were found between classroom performance ratings and ATMI total scores or subscales. Only the self-confidence ATMI subscale correlated significantly with Global Scholar scaled scores.

- Hypothesis: Students' self-assessments (survey responses) and teacher assessments (grades) of their mathematical content knowledge are expected to have a strong positive correlation.

  Conclusion: No significant correlations were found between students' self-assessment scores and teachers' classroom performance scores.

- Hypothesis: Students' levels of self-confidence, value, enjoyment, and motivation in mathematics will significantly increase after one semester of participation in project-based learning.

  Conclusion: No statistically significant increases were observed in any of the above-mentioned ATMI subscales, nor in ATMI total scores.

Conclusions and Recommendations

Student engagement emerges as a critical component for successful implementation of project-based learning in middle grades mathematics classrooms. Engagement levels often drop off in older grade levels as compared to younger grades – this fact combined with mathematical concepts becoming progressively difficult and complex can make it difficult for teachers in higher grade levels to keep students interested in course material as they progress. PBL requires authentic connections to the real world, and when those connections are forced or artificial, students are less active in their learning. Students should be engaged in more long-term projects that arise from their own interests and curiosities.

Recommendations for assessment include the following:

- Incorporating the use of peer assessments to give students a more prominent voice in the assessment process and to reflect differing roles in group projects.
- Placing more importance on student self-assessment ratings. The statistically significant correlation between ATMI self-confidence subscores and Global Scholar standardized test scores demonstrates that students are able to successfully gauge their own levels of learning in mathematics. Teachers could consider student self-assesments when determining classroom performance grades, which currently seem to be lacking in consistency across grade levels.

Findings in this study should help the school system involved to identify strengths and weaknesses of their mathematics PBL middle grades instructions. Discrepancies in levels of fidelity of implementation across grade levels should lead to more comprehensive teacher training and professional development to ensure uniformity across grade levels. Classroom performance ratings could also be more uniform across grade levels. Project-based mathematics learning is generally alive and well in the school, but technology could be implemented more frequently and in ways that are more organic to students' interests and curiosities. This knowledge should also benefit educators in similar settings, namely mathematics classrooms in rural public schools looking to implement mathematics PBL instruction and assessment.

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Appendix A

School Mission, Beliefs and Vision, 2016

The strength of (School Name) is grounded in our sincere desire to create a culture of intellectual curiosity. We are fearless about doing what is best for our students. We refer to how we do things as **“The (School Name) Way.”**

Our Mission: To create a **culture of intellectual curiosity** where all students have **ownership over their learning** and are inspired to **think, innovate,** and **create.**

Our Vision: Our students are **lifelong learners** who use their knowledge, skills, and influence to make the world a better place.

Our Beliefs:

We believe intellectual growth occurs when learners are **genuinely engaged** in their learning.

We believe students are more engaged when they are **solving real problems** for a real audience.

We believe meaningful learning can occur **any time** and at **any location.**

We believe learners will do challenging work when **failure** is embraced as a valuable part of the learning process and they **feel safe and valued.**

We believe community members are **valuable partners** and must be **involved** in their schools.

We believe all members of the school community should treat each other like **family.**

We believe that every member of the school community contributes to student learning and should be a **continuous learner.**

We believe teachers are **designers, facilitators, navigators, mentors, encouragers,** and **leaders** who continuously work on improving the learning experiences designed for students and are highly respected experts who have a global impact on teaching and learning.

We believe parents are **valuable partners** and members of the school community.

We believe the superintendent and principals are **lead learners** and are highly respected experts who have a global impact on teaching and learning.

We believe the superintendent and school board function as a **team**, advocate for students, create capacity and build community.

Appendix B

Attitudes Toward Mathematics Inventory

Name: ______________________________

Community: ______

Directions: Read each sentence carefully and think about how you feel. Choose the option that best describes your feelings about the statement. There are no right or wrong answers, and your teacher will not see your answers. Please answer every question.

Scale: 1 – Strongly Disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, 5 – Strongly Agree.

1. Math is an important and necessary subject.
2. I want to improve my math skills.
3. I feel good when I solve a math problem.
4. Math helps develop the mind and teaches a person to think.
5. Math is important in everyday life.
6. Math is one of the most important subjects for people to study.
7. High school math classes would be very helpful no matter what kind of job I want.
8. I can think of many ways that I use math outside of school.
9. Math is one of my most dreaded subjects.*
10. My mind goes blank and I can't think clearly when doing math.*
11. Studying math makes me feel nervous.*
12. Math makes me feel uncomfortable.*

13. I am always under a terrible strain in math class.*

14. When I hear the word math, I have a feeling of dislike.*

15. It makes me nervous to even think about doing a math problem.*

16. Math does not scare me at all.

17. I have a lot of self-confidence when it comes to math.

18. I am able to solve math problems without too much trouble.

19. I expect to do fairly well in any math class I take.

20. I am always confused in my math class.*

21. I feel a sense of insecurity when attempting math.*

22. I learn math easily.

23. I think I could learn advanced math.

24. I have usually enjoyed studying math in school.

25. Math is dull and boring.*

26. I like to solve new problems in math.

27. I would rather do a math assignment than write an essay.

28. I would like to avoid using math in high school.*

29. I really like math.

30. I am happier in a math class than in any other class.

31. Math is a very interesting subject.

32. I am willing to take more math classes than I have to.

33. I want to take as many math classes as I can in school.

34. I like the challenge of doing math.

35. I think studying advanced math is useful.

36. I believe studying math will help me with other kinds of problem solving.

37. I feel comfortable expressing my own ideas about how to solve a difficult math problem.

38. I feel comfortable answering questions in math class.

39. A strong math background can help me later in my job.

40. I believe I am good at solving math problems.

* Items reverse-scored.

Appendix C

Supplemental Survey Questions

1. I like to come up with new ways to solve math problems.
2. I believe that there is usually only one right way to solve math problems.*
3. My teacher asks me to explain how I got my answers to math problems.
4. In math class, we practice things over and over until we get them right.*
5. I work on math problems during class time with other students in my class.
6. My teacher tries to understand my way of doing math problems.
7. My teacher asks me to show my work with pictures.
8. We do projects that are graded.
9. In math class, we work on one big math problem for a long time.
10. My teacher shows us how to solve math problems, and then we practice similar problems.
11. My teacher is interested in my work even if it is wrong.
12. When I don’t understand something, my teacher tries to help me by asking questions about my thinking.
13. My teacher asks us to think about different ways to solve each math problem.
14. I am able to show my teacher how much I know about math.
15. I am able to show my classmates how much I know about math.
16. I spend time at home doing math on my own.
17. I spend time at home learning about math-related topics.

18. I feel like I need extra help to stay caught up in math class.*

19. I am able to learn how to do math problems presented during class.

20. I am able to explain to others how to do math problems.

* Items reverse-scored.

Appendix D

Teacher Post-Semester Survey

Directions: Please indicate the extent to which you agree or disagree with the following statements, and provide any other relevant comments that you wish to share.

Scale: 1 – Strongly Disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, 5 – Strongly Agree.

1. I am able to determine my students' mathematical abilities based on their contributions to class-wide projects.

   Comments:

2. I am able to determine my students' mathematical abilities based on their contributions to small group projects.

   Comments:

3. I am able to determine my students' mathematical abilities based on individual projects or assignments.

   Comments:

4. It is important to teach students how to solve math problems through practical, real world applications.

   Comments:

5. It is important to teach students the theoretical, pure mathematics behind the processes they are learning.

   Comments:

6. Students in my class have opportunities to vocally express their understanding of mathematical concepts.

   Comments:

7. Students in my class have opportunities to express their understanding of mathematical concepts through writing.

   Comments:

8. Students in my class have opportunities to express their understanding of mathematical concepts through creative outlets in visual, musical, or other performing arts.

   Comments:

Appendix E

Classroom Observation Protocol: Study of STEM Learning

Observer/Interviewer:__________________ School Name:_______________

Observation date: _____________ Time Start: _________ End: ______

Teacher Ethnicity: _____ Teacher Gender: Male___Female_

Grade Levels of students:________Course Title:_______________________

Students: Number of Males______ Number of Females______

Classroom Race/Ethnicity: % Minorities (approximate) ____________

Please give a brief description of the class observed, including:

- the classroom setting in which the lesson took place (space, seating arrangements, environment and personalization, *etc.*),
- when in the overall lesson sequence this class takes place (toward the beginning of a unit, in the middle of a unit, toward the end)
- any unusual context of the lesson (interruptions, etc.)

Use diagrams if they seem appropriate.

Lesson Topic:

Lesson Goals as presented *by the teacher to the students*:

Curriculum Materials Used: (include any textbook, lab materials, or resources used)

Lesson Structure: Briefly describe the structure of the lesson (e.g. 5 min quiz, followed by 25 min of homework review, followed by 10 min of whole class discussion, followed by 15 min individual work on worksheets; note whether there was a conceptual summary at the end of the lesson; if summative assessment is present, please describe).

As implemented, the lesson mostly focused on (most time was spent on):

- Most time spent on practicing algorithms/basic skills and procedures/vocabulary
- About equal time spent on practicing algorithms/basic skills and procedures/vocabulary and on concept development and meaningful learning
- Most time spent on inquiry/meaningful learning and genuine problem solving

1. Mathematics and Science Content

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation. DK = Observer does not know or is not able to make this determination.

1a. Math and science content information was accurate.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1b. Teacher's presentation or clarification of mathematics or science content knowledge was clear.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1c. Teacher used accurate and appropriate mathematics or science vocabulary.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1d. Teacher/students emphasized meaningful relationships among different facts, skills, and concepts.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1e. Student mistakes or misconceptions were clearly addressed (emphasis on correct content here).	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1f. Teacher and students discussed key mathematical or science ideas and concepts in depth.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1g. Teacher connected information to previous knowledge.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1h. Appropriate connections were made to other areas of mathematics/science or to other disciplines.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1i. Appropriate connections were made to real-world contexts.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
Summary: Quality of Mathematics and Science Content	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Record specific examples below.

2. Student Cognitive Engagement in Meaningful Instruction

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

2a. Students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2b. Students were asked to explain or justify their thinking.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2c. Students were given opportunities to summarize, synthesize, and generalize	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2d. Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2e. Students were asked to apply knowledge to a novel situation.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2f. Students were asked to compare/contrast different answers, different solutions, or different explanations/interpretations to a problem or phenomena	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Quality of Student Cognitive Engagement in Meaningful Instruction	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

3. Inquiry learning; Project-based learning; and Problem-based instruction

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation. NA = not applicable to activity being observed (since projects may not occur in every lesson)

3a. Students were engaged in open-ended tasks or questions.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3b. Students engaged in hands-on or real-life problem solving activities or a lab experiment.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3c. Students developed their own questions and/or hypotheses to explore or test.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3d. Students engaged in scientific inquiry process (tested hypotheses and made inferences)	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3e. Students determined which problem-solving strategies to use.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3f. Students had to present or explain results of project.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3g. Students worked on a project requiring creativity.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3h. There was an explicit evidence of teacher modeling engineering (or reverse engineering) design process.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3i. There was an explicit evidence of students using engineering (or reverse engineering) design process.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
Summary: Quality of Inquiry learning; Project-based learning; and Problem-based instruction	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Record specific examples below.

4. Teacher Instruction/ Formative Assessment

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

4a. Teacher provided clear learning goals to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4b. Teacher provided clear criteria for success/examples of good work to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4c. Teacher used a variety of strategies to monitor student learning and understanding throughout the lesson.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4d. Teacher provided specific feedback to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4e. Students were engaged in self- and/or peer-assessment.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4f. Teacher adjusted or differentiated instruction based on evidence of student learning.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4g. Students were given opportunities to reflect on their own learning.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
Summary: Quality of Teacher Instruction/ Formative Assessment	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐

Record specific examples below.

5. Common Instructional Framework

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

5a. Students worked collaboratively in teams or groups.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	
5b. Students used writing to communicate what they had learned.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	
5c. Teachers asked open-ended questions that required higher level thinking.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	
5d. Teachers provided assistance/scaffolding when students struggled.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	
5e. Students engaged in discussion with each other.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	
5f. Students participated in guided reading discussions.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
Summary: Overall rating of Quality of Common Instructional Framework implementation	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Record specific examples below.

6. Student Engagement

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

6a. Students were behaviorally engaged (following directions, on-task behavior, responding to teachers' questions).	(0) ☐	(1) ☐	(2) ☐	(3) ☐
6b. The time in class was spent productively on meaningful tasks.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
6c. Teacher pursued the active engagement of **all** students.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
6d. Students appeared cognitively engaged (ask questions of the teacher and each other related to the content and ideas being discussed, follow up on each other's responses, clear evidence of students working/thinking hard on a problem).	(0) ☐	(1) ☐	(2) ☐	(3) ☐
6e. Students showed perseverance when solving math/science problems.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Student Engagement	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

7. Use of technology

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

7a. Technology was used to a high extent (as a proportion of time of the lesson and intensity of use)	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7b. Students used technology to explore or confirm relationships, ideas, hypotheses, or develop conceptual understanding.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7c. Students used technology to generate or manipulate one or more representations of a given concept or idea.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7d. Students used technology as a tool to meet a discreet instructional outcome (like an assignment or specific objective).	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7e. Students used technology to practice skills or reinforce knowledge.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7f. Technology was used but did not appear to provide any added benefit.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7g. Teacher used technology to achieve instructional goals. (Emphasis on the "teacher" here)	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Use of technology	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

8. Classroom Culture

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

	(0)	(1)	(2)	(3)
8a. Students exhibited positive classroom behavior.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
8b. The classroom exhibits a respectful environment.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
8c. There is a climate of respect and encouragement for students' ideas, questions, and contributions; mistakes are viewed as an opportunity to learn	(0) ☐	(1) ☐	(2) ☐	(3) ☐
8d. Students and teacher appear to have positive relationships and to enjoy spending time with each other (laughing, easy relationship).	(0) ☐	(1) ☐	(2) ☐	(3) ☐
8e. Students actively seek and provide assistance or guidance.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
8f. Teachers and students provide positive reinforcement and feedback to each other.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Classroom Culture	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

Appendix F

IRB Approval Documents

Thu 9/22/2016 10:31 AM
IRB Administration irbadmin@auburn.edu
Approval, Protocol #16-297 MR 1609
To: Brittany McCullough
Cc: David Shannon

Dear Ms. McCullough,

Your protocol entitled "Examining the Validity of Project-Based Mathematics Learning Assessment" has received approval as "Minimum Risk" under federal regulation 45 CFR 46.110.

Official notice:
This e-mail serves as official notice that your protocol has been approved. A formal approval letter will not be sent unless you notify us that you need one. By accepting this approval, you also accept your responsibilities associated with this approval. Details of your responsibilities are attached. Please print and retain.

Informed Consent:
Attached is a scan of your new, stamped informed consents. You must provide a copy for each participant to keep. Also attached is a copy of your approved protocol.

Expiration:
Your protocol will expire on September 13, 2017. Put that date on your calendar now. About three weeks before that time you will need to submit a final report or renewal request.

When you have completed all research activities, have no plans to collect additional data and have destroyed all identifiable information as approved by the IRB, please submit a final report.

If you have any questions, please let us know.
Best wishes for success with your research!

Selena Hathcock
Office of Research Compliance
115 Ramsay Hall
Auburn University, AL 36849
334-844-5966

AUBURN UNIVERSITY

The Auburn University Institutional Review Board has approved this Document for use from 09/14/2016 to 09/13/2017
Protocol # 16-297 MR 1609

(Note: Do not agree to participate unless an approval stamp with current dates has been applied to this document.)

PARENTAL PERMISSION
for a Research Study entitled "Examining the Validity of Project-Based Mathematics Learning Assessment"

Your son or daughter is invited to participate in a research study to examine how project-based mathematics learning is measured and assessed. The study is being conducted by Brittany McCullough, PhD student under the direction of Dr. David Shannon, Professor in Auburn University's Department of Educational Foundations, Leadership and Technology. Your son or daughter is invited to participate because he or she is a student in Community 6, 7, or 8 at Pike Road School. Since he/she is age 18 or younger, we must have your permission to include him/her in the study.

What will be involved if your son/daughter participates? If you decide to allow him/her to participate in this research study, he/she will be asked to complete two online surveys during the Fall 2016 semester. The surveys will ask questions about the students' attitudes and opinions regarding mathematics and will take approximately 30 minutes each. His/her classroom will also be observed by Ms. McCullough six times over the course of the semester, and mathematics grades and test scores will be collected anonymously from the school. Your son's/daughter's total time commitment will be approximately one hour and all study activities will take place during school.

If you (or your son/daughter) change your mind about his/her participation, he/she can be withdrawn from the study at any time. His/her participation is completely voluntary.

Your son's/daughter's privacy will be protected. Any information obtained in connection with this study will remain confidential. The data collected will be protected by code names and password-protected files. Information obtained through his/her participation may be used to fulfill an educational requirement or published in a professional journal. No identifiable information will be published.

If you (or your son/daughter) have questions about this study, please contact Brittany McCullough at bnw0005@auburn.edu or David Shannon at shanndm@auburn.edu. A copy of this document will be given to you to keep.

If you have questions about your child's rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone at (334) 844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH FOR YOUR SON OR DAUGHTER TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO ALLOW HIM OR HER TO PARTICIPATE.

Parent/Guardian Signature	Date	Investigator obtaining consent	Date
Printed Name		Printed Name	

A LAND GRANT UNIVERSITY

AUBURN UNIVERSITY

(Note: Do not agree to participate unless an approval stamp with current dates has been applied to this document.)

STUDENT ASSENT
for a Research Study entitled "Examining the Validity of Project-Based Mathematics Learning Assessment"

Dear Student:

You are invited to participate in a research study to help us understand how project-based mathematics learning is measured and assessed.

If you decide you want to participate, you will be asked to complete two surveys during this semester. The surveys will ask questions about your attitudes and opinions regarding mathematics and will take about 30 minutes each. Someone will also visit your classroom once every two weeks and take notes so that we can see what happens during your math classes and how your teachers are able to measure what you have learned, and your mathematics grades and test scores will be collected anonymously from the school.

You can decide at any time that you do not want to participate or complete the surveys. No one will be angry with you if you decide not to participate. Your responses to the surveys will be kept confidential, and your name will never be used in any way.

If you have any questions about what you will do or what will happen, please ask Mrs. McCullough now. If you have any questions later, we want you to ask.

If you have decided to help us with this study, please sign and print your name on the lines below.

Student Signature Date	Investigator obtaining consent Date
Printed Name	Printed Name

The Auburn University Institutional Review Board has approved this Document for use from 09/14/2016 to 09/13/2017
Protocol # 16-297 MR 1609

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(Note: Do not agree to participate unless an IRB approval stamp with current dates has been applied to this document.)

TEACHER INFORMED CONSENT
for a Research Study entitled "Examining the Validity of Project-Based Mathematics Learning Assessment"

You are invited to participate in a research study to examine how project-based mathematics learning is measured and assessed. The study is being conducted by Brittany McCullough, PhD student under the direction of Dr. David Shannon, Professor in the Auburn University Department of Educational Foundations, Leadership and Technology. You are invited to participate because you are a mathematics lead learner in Community 6, 7, or 8 at Pike Road School and are age 18 or older.

What will be involved if you participate? Your participation is completely voluntary. As a participant, you will be asked to allow me to observe your classroom once every two weeks over the course of the semester (six observations total, which will be scheduled with the researcher in advance); complete an online survey at the end of the semester asking about your attitudes and opinions regarding assessment techniques for project-based mathematics learning; and allow me to survey your students twice during the semester – once at the beginning of the semester and once near the end of the semester. Your total time commitment would be about 30 minutes to complete the end-of-semester survey. No preparation or time commitment is necessary from you for the classroom observations.

Any data obtained in connection with this study will remain confidential. We will protect your privacy and the data you provide by removing any identifiable information. Your survey responses and classroom observation data will be kept private, and your name will never be used in any way. Information collected through your participation may be used to fulfill an educational requirement or presented at an educational conference or published in a professional journal.

If you have questions about this study, please contact Brittany McCullough at bnw0005@auburn.edu or David Shannon at shanndm@auburn.edu. A copy of this document will be given to you to keep.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone at (334) 844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@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

____
Printed name

____
Investigator obtaining consent Date

____
Printed name

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Protocol # 16-297 MR 1609

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