Impact on Student Academic Performance of a Self-Directed Primer E-Book in a Follow-On Organic Chemistry Course

by

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Abstract

Retention of knowledge from school courses has long been a concern of educators and administrators. Bahrick (1979) offered the general sentiment that "much of the information acquired in classrooms is lost soon after final examinations" (p. 297). This negative outcome is exhibited in curriculum that feature course sequences, where mastery of concepts from the first course is required to achieve success in the follow-on course.

This quasi-experimental, quantitative study measured the impact of developing a primer e-book delivered using self-directed learning, a key concept of adult education, to students who enroll in the second organic chemistry course in a two-semester sequence. Demographic and achievement data including gender, race, admission type, cumulative GPA, standardized test scores, academic major, and grade in Organic Chemistry I were retrieved for students who attempted Organic Chemistry II over 13 terms between Fall 2014 and Fall 2018 ($N = 2{,}099$). Students in several sections ($N = 1{,}279$) were provided a self-directed primer e-book with key concepts from the previous course.

For research question 1, backward elimination regression was used to determine which factors significantly impacted student performance on a comprehensive final exam. For research question 2, those factors were controlled and a hierarchical multiple regression was used to determine if use of the e-book had a significant impact on the comprehensive final exam score. For research question 3, ANCOVA was used to determine if using the self-directed primer e-book disproportionately impacted student performance based on gender or grade in Organic Chemistry I.

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List of Abbreviations

CIP	Classification of Instructional Programs
GPA	Grade Point Average (Cumulative)
IPEDS	Integrated Postsecondary Education Data System
NCES	National Center for Education Statistics
OC1	Organic Chemistry I
OC2	Organic Chemistry II
SDL	Self-Directed Learning
SPSS	Statistical Package for Social Sciences
STEM	Science, Technology, Engineering, and Mathematics

CHAPTER 1: INTRODUCTION

Background

Retention of knowledge from school courses has long been a concern of educators and administrators. Bahrick (1979) offered the general sentiment that "much of the information acquired in classrooms is lost soon after final examinations" (p. 297). Custers' (2010) review of long-term retention of basic science knowledge reinforced the belief that students forget a large portion of what they learned in school.

Knowledge attrition has a negative impact on learner success as students advance through a curriculum. "Professors expect students to remember the topics taught in previous courses, and to build upon these concepts" (Taylor, Olofson, & Novak, 2017, p. 97). The basis of most constructivist models of education is building upon prior knowledge by adding onto an existing mental framework (Bodner, 1986). Semb and Ellis (1994) found most studies on knowledge retention take place in laboratory settings, which differ from classroom learning in that classroom learning takes place over several months with instructional content that is more meaningful, varied, detailed, and complex.

For adult learners, accumulated life experience plays a significant role in their learning of new concepts (Knowles, 1980, p. 44). Since life experiences are varied, self-directed learning as an instructional process and strategy allows learners to make a stronger and deeper connection with the content being studied. Knowles described self-directed learning as "a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes" (Knowles, 1975b, p. 18). Two reasons Knowles (1975a) mentions in support of self-directed learning are: (1) active learners who take an initiative to learn are more likely to retain knowledge than passive learners; and (2) taking initiative is more aligned with maturing psychological development. Knowles (1975a) identifies four stages of self-directed learning, particularly for academic learning: (1) defining the task at hand; (2) setting goals and planning for those goals; (3) determining study strategies and practices; and (4) metacognitive reflection to adapt studying. Self-directed learning as an instructional strategy is an approach which creates the psychological climate that "causes adults to feel accepted, respected and supported" (Knowles, 1980, p. 47) and there is a "spirit of mutuality between teachers and students as joint inquirers" (Knowles, 1980, p. 47).

The use of electronic books, or e-books, to deliver content can allow students to access and use the content at on their own time and location, further supporting self-directed learning instructional strategies. In several studies, students preferred the use of e-books and cited an e-book's 24/7 availability and portability as strong reasons for the preference (Carroll, Corlett-Rivera, Hackman, & Zou, 2016; Chelin et al., 2009; Shelburne, 2009). Older definitions of the word e-book limited the authors to electronic versions of physical books; however, newer understandings of the evolving technology of e-books recognize them as digital publications with unique user experiences such as flowing text, interactive graphics, built-in glossary, keyword searching, and notetaking.

As the use of e-books grows, Muir and Hawes (2013) make the case that "for librarians and academics, the onus is on developing skills for effective use of e-books" (p. 272), and propose a typology that addresses the "requirements of library/academic instruction to develop the necessary e-book literacy skills to achieve [the effective use of academic e-books]" (p. 272).

Statement of Problem

Successfully completing organic chemistry is generally required for college students who are pursuing careers in science, technology, engineering, or mathematics (STEM), including students majoring in chemistry, biology, nursing, pharmacy, chemical or industrial engineering, or public health. Students in one study reported "premedical science courses, principally chemistry, as the main factor discouraging their continued premedical interest" (Barr, Matsui, Wanat, & Gonzalez, 2010, p. 46). Additional studies also showed that these negative experiences in chemistry disproportionately impact women and underrepresented minority groups, leading Barr, Gonzalez, and Wanat (2008) to "reasonably conclude that the negative influence of chemistry courses on continued interest in premed is experienced more so by women and underrepresented minority students" (p. 510).

Since organic chemistry follows general chemistry in curriculum, these negative experiences may be attributed to students taking organic chemistry courses after varying paths through general chemistry: students may have completed Advanced Placement general chemistry in high school and used a high AP chemistry exam score to receive college credit for general chemistry, or students may have completed some chemistry courses at a community college prior to transferring to a four-year university. These incongruous paths through foundational knowledge acquisition create a challenge for instructors teaching specific subject matter.

When a high number of students perform poorly in organic chemistry, for example withdrawing from the course or earning a grade of D or F (collectively referred to as DFW), it "generates a large demand for off-sequence course offerings" (Fischer, Zhou, Rodriguez, Warschauer, & King, 2019, p. 857) and the additional courses for the repeating students "pose substantial logistical challenges to the department as personnel and space capacity for the simultaneously offered laboratory sessions are limited" (Fischer et al., 2019, pp. 857–858) or the students opt to change majors, which may delay their degree completion time and increase their cost of attendance.

Purpose of the Study

The purpose of this study was to determine the impact of a self-directed learning intervention in the form of a primer e-book on academic performance in a follow-on organic chemistry course. Measuring this impact over several years and across multiple student characteristics can potentially provide an instructional strategy to improve student academic performance. The student characteristics used for this study included gender, race, admission type, cumulative GPA, standardized test scores, academic program of study, and grade in the first organic chemistry course.

Research Questions

The following research questions were used in this study:

1. What student characteristics including gender, race, admission type, cumulative GPA, standardized test scores, academic major, and grade in Organic Chemistry I, have a significant impact on the grade on a comprehensive final in an Organic Chemistry II course?
2. Controlling for the student characteristics that have a significant impact on the grade on a comprehensive final in an Organic Chemistry II course, is there a significant difference on the grade on a comprehensive final as the result of using a self-directed primer e-book?
3. Is there a significant difference in final exam performance for students based on gender or grade in Organic Chemistry I?

Significance of the Study

As consumers of higher education question the effectiveness of an investment in college education, higher education institutions are establishing ways to ensure that students are achieving academic success and completing degrees at an efficient time and cost. One way of reducing time to completion and reducing cost is to ensure students are better prepared for the courses that they are required to take in their chosen programs of study. As a result of being better prepared, students are less likely to earn DFW grades in courses, which reduces the need for re-taking the course and paying for it more than once. Organic chemistry is one course sequence that provides a challenge to students.

Several studies explored strategies for better preparing students for the rigor of organic chemistry. Fisher et al. (2019) at University of California Irvine measured the impact on academic performance in organic chemistry as a result of a three-week online preparatory course. Their study provided the preparatory course at the beginning of the one-year organic chemistry course sequence, but it did not measure knowledge retention from the first course in the sequence to the second organic chemistry course. Schnoebelen (2018) evaluated whether curricular reform, which refers to the content that is taught, impacted student success but did not evaluate pedagogy or andragogy, which refers to *how* the content is taught (p. 33). Better understanding how a self-directed primer e-book impacts learning from the first course in a sequence to a second will allow better support of student success in challenging course sequences.

Limitations and Delimitations

This study had several limitations and delimitations. The primary limitation was that aside from the use of a primer e-book at the beginning of several course sections over 13 academic terms, there was no control over instructors' pedagogical decisions to teach their sections of organic chemistry. No effort was made to evaluate or grade the teaching ability of the instructors for the set of organic chemistry course sections used in this study. This study exerted no control over the grading decisions made by faculty. There was no effort to separate the effect of the e-book from the effect of any other preparatory material.

The study was conducted over 13 consecutive semesters, including spring, fall, and summer. The summer terms were about two-thirds the length of a spring or fall term. Sizes of course sections were the decision of the department based on enrollment demand and availability of faculty.

A further limitation was that the study was at one institution in the southeastern United States. Further research that incorporates a randomized and representative sample must be completed to apply the results broadly.

While further research could inform the applicability of using a self-directed primer e-book to impact follow-on courses in other disciplines, this study was delimited specifically to Organic Chemistry II (OC2), the subsequent and final course in a two-course, two-semester organic chemistry sequence.

Assumptions of the Study

This study was based on several assumptions. One was that the comprehensive final exam administered at the end of an OC2 course was a proxy for authentic measurement and assessment of student academic performance in OC2. Since classes are taught at different times on different days, this study also assumed that changes to physical classroom, time of day, and day of week did not have a statistically significant impact on student performance on the final exam. Another key assumption was that the instruction in OC2 by nine different instructors over

13 terms did not create an impact on how the student learned content covered on a comprehensive final exam.

Definitions of Terms

The following terms are used within and throughout this study:

1. Adult education – an academic discipline reflecting a "specific philosophy about learning and teaching based on the assumption that mature learners can and want to learn, that they are able and willing to take responsibility for that learning, and that the learning itself should respond to their needs" (Draper & English, 2017; Knowles, 1980).
2. Andragogy – "the science and art of helping maturing human beings learn" (Knowles, 1975a, p. 85).
3. Cumulative GPA - the number of grade points earned throughout a student's course of study on a four-point scale divided by the total number of course credit hours completed by the student. While some calculations of grade point average (GPA) disregard failing grades once a course is re-taken, the cumulative GPA includes the failing grades to provide a fuller indication of academic achievement.
4. ePub – Short for electronic publication, ePub is a file format that adheres to the technical standard established by the International Digital Publishing Forum (now part of W3C) and endorsed by Book Industry Study Group, Inc., as the preferred format for electronic books. EPub files can be viewed on a wide number of electronic devices including computers, tablets, e-readers, or smartphones (Ivan Herman, 2019).
5. Failing grade – in an academic course, a letter grade of D or F.

6. Follow-on course – in a curricular course sequence, the course that is taken subsequent to the first course. For example, OC2 is the follow-on course for OC1, and together the two courses comprise the organic chemistry curricular sequence.
7. Organic chemistry – a subdiscipline of chemistry that is the "study of the structure, properties, composition, reactions, and preparation of carbon-containing compounds" (American Chemical Society, n.d.)
8. Passing grade – in an academic course, a letter grade of A, B, or C.
9. Race – one or more self-reported categories by students including American Indian or Alaskan native, Asian, black or African American, native Hawaiian or other Pacific Islander, or white (Andrea Sykes, 2012).
10. Self-directed – An instructional strategy that allows the learner to take control of their knowledge attainment by (1) defining the task at hand; (2) setting goals and planning for those goals; (3) determining study strategies and practices; and (4) metacognitive reflection to adapt studying (Knowles, 1975a).
11. Standardized test score – the subject-based or cumulative score on the SAT or ACT college entrance exams.
12. Transfer student – a student at the four-year institution where this study was conducted who completed one or more credit hours in the same degree level at another institution prior to enrolling at the current institution. Transfer students may have completed credits at one or more two-year community colleges or other four-year institutions.

Organization of the Study

This study is divided into five chapters. Chapter 1 introduces the study by providing background information, statement of the problem, purpose of the study, research questions, limitations and assumptions, and definition of terms. Chapter 2 is a review of related literature divided into six sections: andragogy and adult education; self-directed learning; knowledge retention; use of e-books in higher education; results on academic performance from instructional interventions such as in-person boot camps, curricular changes, online homework, active learning, and flipped classrooms; and the impact of a range of learner characteristics on academic performance including: gender, race, admission type, cumulative GPA, standardized test scores, academic program of study or major, and grade in the first course of a course sequence. Chapter 3 reports the procedures utilized in this quantitative study, including the population and sample, data collection, and the plan for data analysis. The results of the study are presented in Chapter 4. Chapter 5 includes a summary of the findings, conclusions, implications and recommendations for further practice and research.

CHAPTER 2: LITERATURE REVIEW

Introduction

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Andragogy and Adult Education

Self-directed learning is a core principle of andragogy, or adult education, and, therefore, an exploration into andragogy is necessary in order to better understand self-directed learning. Knowles (1975a) defined the term andragogy as "the science and art of helping maturing human beings learn" (p. 85). The Greek word *aner*, which means adult, forms the root of andragogy. In contrast, pedagogy is the science and art of teaching children, and is formed with the Greek root words *paid* and *agogus*, which mean child and leading, respectively (Knowles, 1980, p. 40). The term *andragogy* was first used to refer to adult education by the German teacher Alexander Kapp in 1833, when he published a book describing Plato's writings about education (Loeng, 2017, p. 629).

Malcolm Knowles, a practitioner and researcher of educating adults, noted that many teachers of adults who published their observations and practices in the *Journal of Adult Education* between 1929 and 1948 expressed guilt because they felt they were violating accepted academic standards and practices that were based on pedagogy. In 1950, Knowles compiled several of these practices in *Informal Adult Education*. He used this book to begin developing unifying theories (Knowles, 1980, pp. 41–42). Knowles is widely recognized as the founder of the modern academic field of adult education since he began tying the term *andragogy* to theories and methods that support educating adults (Loeng, 2017). The theories and methods that form the basis of andragogy are based on six key assumptions of how children and adults differ in learning: Adult learners (1) need a reason for learning, (2) are self-directed, (3) bring prior experience to the learning activity, (4) possess a readiness to learn, (5) hold a problem- or performance-centered orientation to learning, and (6) are intrinsically motivated (Knowles, Holton III, & Swanson, 2005, pp. 57–58).

While andragogy may specifically refer to adults, it is worth noting that there is no strict age requirement for the application of these assumptions. From the learner-centric view, the difference is with the maturity of the learner, as supported by Houle: "The university is distinguished from the kindergarten chiefly by the difference in the maturity of the student, and adult education is distinguished in the same way from the schooling provided to children and youth" (Houle, 1961, p. 81). The andragogy assumptions can be used to develop learning that is more effective for mature learners because "they provide a sound foundation for planning adult learning experiences" (Knowles et al., 2005, p. 157).

Characteristics of Adult Learners

The theories and methods that form the basis of andragogy are based on six key assumptions of how children and adults differ in learning. The assumptions are discussed below as a comparison between andragogy and pedagogy.

The first assumption is that adult learners need to know why they are learning something before they undertake the learning activity, and thus adults are critical of what they are asked to learn (Knowles et al., 2005, p. 64). Children learn for the sake of learning, often because the teacher is teaching them particular content (Beebe, Mottet, & Roach, 2013, p. 33). This shift in maturity of the learner asking why something is important before learning it is the basis in the shift to andragogical practice. Prior to developing learning for adults, an instructor could complete a needs assessment, which is a process of "identifying what learners do not yet know or the necessary skills that they can't yet perform" (Beebe et al., 2013, p. 35). This will allow the course developer to build courses or training that are more relevant. Instructors could also take care to explain the purpose of an assignment and its expected learning outcome (Cochran & Brown, 2016, p. 77).

The second assumption is that as learners mature, their personalities shift from a dependent role to a self-directed role (Knowles et al., 2005, p. 65). Beebe et al. (2013) link this assumption to self-awareness, asserting "adults know their own deficiencies, and they know what they need to learn to become successful" (p. 33). Shifting from a teacher-centered to a learner-centered approach allows for students to take more control of their learning and allows the instructor to be a facilitator (Smart, Witt, & Scott, 2012). As an example, Smart et al. (2012) asked students in a business communication course to draw their own communication models first and then asked the students to compare their illustrations with accepted models, rather than lecture on only the accepted models. Knowles' (1980) work three decades prior supports this approach which creates the psychological climate that "causes adults to feel accepted, respected and supported" (p. 47) and creates a "spirit of mutuality between teachers and students as joint inquirers" (p. 47).

The third assumption is that adults have an accumulated life experience, unlike children, and this experience can be a valuable resource for themselves and their co-learners (Knowles, 1980, p. 44; Knowles et al., 2005). One of the key points in Bain's (2004) synthesis of research on how humans learn is that when "we encounter new material, we try to comprehend it in terms of something we think we already know" (p. 26). When developing learning for adults, Knowles (1980) states, experiential techniques such as "laboratory experiments, discussion, problem-solving cases, and simulation exercises" (p. 44) are ideal primary techniques, with the emphasis on participation (p. 50). Students who actively participate and contribute to their learning will be more engaged and motivated to learn (Harper & Ross, 2011).

Regarding the fourth assumption, Knowles (1980) utilizes the research of Robert J. Havinghurst, a contributor to the understanding of human development and aging, to identify ten social roles for adults: worker, mate, parent, homemaker, child of aging parents, citizen, friend, organization member, religious member, and user of leisure time. Knowles then posits that as children have development phases with corresponding learning, adults have development phases around their social roles (p. 51). As adults identify transition points or crises in those roles, they seek learning. As a result, those developing learning for adults should identify teachable moments around these transitions or crises and encourage grouping of learners based on these roles, either heterogeneous or homogenous groups, depending on the skill to be learned (p. 53).

The fifth assumption is that adults are problem-centered or performance-centered, meaning they want to be able to apply their learning immediately (Knowles, 1980). This is in contrast with children, who are subject-centered in their learning, meaning children tend to build up their knowledge over time in different subjects in order to use that learning in the future (Knowles, 1980). A practical way to recognize this difference in learning orientation is instead of telling the student what they will learn in the course, ask the learner what do they hope to get out of this course (Knowles, 1980, p. 54).

Table 1

Six Key Assumptions of Characteristics of Adult Learners

Characteristic	Shift from Pedagogical Approach to Andragogical Approach
(1) Need to know	Learners shift from pedagogical goals of acquiring information to andragogical goals of learning for a specific need.
(2) Self-concept	Learning shifts from pedagogical model of teacher-directed to the andragogical model of self-directed.
(3) Experience	Pedagogical approach cannot rely on the learner's prior experience, but in andragogy lived experience becomes more relevant to learning.
(4) Readiness	Learning shifts from the pedagogical approach of curriculum being society-driven to the andragogical approach of learning that is relevant to roles served by adults.
(5) Learning orientation	Learning shifts from subject-centered in pedagogy to problem-centered or performance-centered in andragogy
(6) Motivation	Pedagogical approach uses external rewards and punishments to provide motivation, whereas andragogical approach recognizes that motivation for adults is intrinsic.

Source: (Knowles, 1980; Knowles et al., 2005).

The sixth assumption about andragogy is that adults are intrinsically motivated to learn (Knowles et al., 2005, p. 58). While pedagogical principles state that children are motivated by external rewards or punishment, a mature learner's drive to improve his or her own condition in life comes from within, such as "increased job satisfaction, self-esteem, their sense of accomplishment, and quality of life issues" (Beebe et al., 2013, p. 36).

Houle's Typology

Cyril Houle (1961) proposed a typology of three categories of adult learners: goal-oriented learners who use education to accomplish a specific objective, activity-oriented learners who wish to participate in an activity without regard for the learning content, and learning-oriented learners who seek knowledge for its own sake. Determining an adult's motivation for learning becomes vital in designing relevant learning, since "understanding why people behave as they do is vitally important to helping them learn" (Wlodkowski & Ginsberg, 2017, p. 2).

An analysis of Houle's typology for the categories of adult learners better enables instructors to design appropriate learning. In 1960, Cyril O. Houle served as the Knapp Visiting Professor at the University of Wisconsin-Milwaukee. To meet his goal to deliver three lectures of campus-wide relevance, he focused on the characteristics of adult learners. The edited versions of these three lectures were published in 1961 in *The Inquiring Mind,* and they become the basis of Houle's typology of classifying adult learners (Williams, 1963).

According to Houle (1961), adult education research primarily focused on characteristics of learners from the perspective of the learning activity (p. 5), and his view was that the field can benefit from learning characteristics of continuing education participants regardless of the specific activity or setting (p. 9). His research was designed to answer six key questions:

> (1) Do continuing learners possess any particular characteristics which make them different from other people? (2) What were the factors that led them to become continuing learners? (3) What has been the history of their continuing education in the past? (4) How much education are they now undertaking, and what kinds? (5) How did they think society views continuing education? (6) How do they themselves view continuing education? (Houle, 1961, p. 83)

The method of data collection used by Houle was interviews of 22 adults identified as active participants at adult learning centers in the Chicago area. Houle, in reference to participants, noted, "They are so conspicuously engaged in various forms of continuing learning that they could be readily identified for me by their personal friends or by the counselors and directors of adult educational institutions" (Houle, 1961, p. 13). Houle then used the focal motivations of these adults to describe three categories of participants in adult education programs: goal-oriented, activity-oriented, and learning-oriented.

Adults classified by Houle as goal-oriented achieved specific objectives through use of learning. A key characteristic of these adults was episodic learning (Houle, 1961, p. 18). Cross (1981) succinctly described learning episodes as having three steps: the adult identifies a specific need or interest, identifies a source of learning for the need, and then participates in the learning activity. The learning activities can be wide-ranging, such as "taking a course, joining a group, taking a trip, or reading a book" (Cross, 1981, p. 82). According to Houle, the goal-oriented adult repeated these episodes and had a "recognition of the need or interest, the will to do something about it, and the opportunity to do so" (Houle, 1961, p. 57). Houle asserted that goal-oriented adults also used learning or education to make a duty a pleasure and provided the example of a participant in his study who was elected to the Board of Education. As a result of this new responsibility, the participant felt the need to attend a classical concert series out of a sense of duty. The participant took classes in music appreciation to gain better understanding of the music and reported actually gaining pleasure in attending future performances (Houle, 1961, p. 17).

Activity-oriented adults participated in a learning activity for the sake of the activity itself, not necessarily to learn a subject matter or a new skill (Cross, 1981, p. 82). Houle (1961) offered a clear description of an activity-oriented learner in action:

> In those evening schools which register their students by having them go to the classrooms on opening night, one will often find people moving along from door to door, peering in to see what kinds of folks are already assembled, and choosing finally to enter

> the class which seems to have the most potentially agreeable group, regardless of the purpose, the content, or the method of the course (p. 20).

From examples of the interviews Houle shared, adults he classified as activity-oriented engaged in learning activities to escape loneliness, find a spouse, or to continue a family tradition. For program administrators interested in learning outcomes data, activity-oriented adults may present a challenge because they are not interested in the actual learning, as a participant in Houle's study expressed: "People that come really want [a friendly atmosphere] as much as learning. Forget about the learning part" (Houle, 1961, p. 19).

In contrast with activity-oriented, learning-oriented adults learned for the sake of learning. Learning-oriented adults have a fundamental desire to learn more and grow as individuals (Cross, 1981, p. 83). A librarian Houle classified as learning-oriented described her learning activities by saying, "Where does education begin and fun stop?" (Houle, 1961, p. 40).

Houle's classification of adult learners based on their characteristics has been important in several ways. First, in the most practical sense, one who is offering learning must define the target audience and seek to understand that audience in order to build effective learning. Determining the motivation of the audience thus becomes a key step in developing and offering learning experiences. Motivation is the reason people behave or think as they do (Wlodkowski & Ginsberg, 2017, p. 2). Houle (1961) stated, "The theory and practice of adult education will not progress very far until they are based on an understanding of how mature people approach the tasks and opportunities of adulthood" (p. 81). Houle's typology thus creates an effective way for the practitioner of adult education to understand how his or her audience approaches the tasks and opportunities of learning.

Houle's typology also spurred additional research to create better understanding of adult learners. When publishing his results, Houle (1961) hoped that his categorizations "will eventually be tested, and broadened, by more rigorous and sharply defined investigations" (pp. 14–15). Houle's study was based on qualitative data, and Boshier (1971) developed a 48-item *Education Participation Scale* in order to quantitatively determine motivational orientations of students in adult education programs. In 1989, Lethbridge used Houle's typology to categorize the motivational orientations of registered nurses in rural New England who return to school to obtain their nursing baccalaureate degree (Lethbridge, 1989). In 2005, Schlesinger published results of interviews with 15 incarcerated African American males who participated in adult education opportunities while imprisoned in the state of Wisconsin (Schlesinger, 2005). Schlesinger determined that the prisoners' motivation for learning was congruent with Houle's categories, classifying most of the participants as goal-oriented or activity-oriented. Houle (1961) stated, "The organized field of adult education...can gain coherence and unified strength only on the basis of common themes, one of the most significant of which is the nature of the adult learner" (p. 81). Houle's typology has contributed to a gaining of coherence and unified strength through multiple researchers scrutinizing their data through the lens of adult learner categories offered by the typology.

The study that formed the basis for Houle's typology is not without criticism. The research sample of interviewees – 22 adults, all living in a specific metropolitan area – was not randomized or representative of a larger population. Houle (1961) himself recognized this limitation:

> An examination of the learning habits of all mankind must wait for another time and a broader investigation. My purpose here is only to mark off for exploration a small part of

> that larger inquiry, hoping not so much to cover even that small sector as to uncover its significance so that it may become the subject of later and fuller development (p. 4).

Boshier (1976) offered a critical view of motivational orientation literature and concluded, “Houle’s typology is elegant and makes subjective sense, but until motivational orientation researchers develop a suitable psychometric procedure to test its validity, it cannot be accepted or rejected as an accurate description of adult learners” (pp. 42–43). Boshier’s (1976) evaluation of multiple motivational orientation literature revealed that “the number of meaningful factors obtained is always greater than three” (p. 41). In 1985, Boshier and Collins tested Houle’s typology by evaluating a large database of many learners, settings, and programs and concluded that while goal-oriented and learning-oriented categories were reasonably accurate, activity-orientation is actually much more complex than Houle envisaged and is instead a forced aggregate of social stimulation, social contact, external expectations, and community service items (Boshier & Collins, 1985). A review of empirical research based on Houle’s 1961 typology led Gordon (1993) to conclude that while Houle’s typology was “a stepping stone for motivational orientation research, the vast unforeseen changes that have taken place in society since its development demand that the typology's relevance to today's motivational orientations of adult education participants be questioned” (p. 3).

Several other frameworks for adult education are also worth exploring for their commonalities and differences from the six characteristics of adult learners described by Knowles.

Eduard Lindeman

Lindeman (1926) posited that adults are motivated to learn as they experience needs that learning will satisfy with orientation to learning being life-centered and that learners start from "situations, not subjects." (p. 8). This aligns closely with Houle's (1961) goal-oriented category and Knowles' (1980) characteristic that adult learners start from a need to know. Lindeman (1926) underscores that experience is the richest source for adults' learning, stating "if education is life, then life is also education" (p. 9). Since experience plays a significant role in adult learning, naturally as age increases, individual differences among people and their learning also increase. Therefore, Lindeman acknowledged that adult learners have a deep need to be self-directing.

Allen Tough

Tough was more concerned with how adults learn rather than why. Tough (1979) based his framework related to mature learners on empirical data from nearly seven years. As a result of this observation, Tough theorized that adults went into a series of intensive phases of learning, similar to Houle's (1961) goal-oriented episodic learning. Tough called these episodes of learning projects. According to Tough, "more than half of the person's total motivation is to gain and retain certain fairly clear knowledge and skill, or to produce some lasting change in himself" (Tough, 1979, p. 6). Tough recommended that effective teaching is to support learners to have effective learning episodes and projects by being able to do them without assistance, thus further supporting the role of self-directed and self-regulated learning for adults, which he referred to as self-planned learning.

Jack Mezirow

Mezirow developed the transformative learning theory that described a "process of effecting change in a frame of reference" (Mezirow, 1997, p. 5). Mezirow asserted that learners change their frame of reference when they encounter a disorienting dilemma. Disorienting dilemmas are experiences that do not fit into a person's current beliefs about the world.

Transformative Learning Theory says that when faced with these disorienting dilemmas, people enter a critical reflection period that may result in their adjusting their world views. Mezirow was not a strong believer in self-directed learning, suggesting that disorienting dilemmas cannot occur without the intervention or guidance of an instructor.

Stephen Brookfield

The adult learning framework described by Brookfield (1981) is based on six key elements: (1) voluntary participation in learning; (2) mutual respect; (3) collaborative spirit; (4) action and reflection; (5) critical reflection; and (6) self-direction (Brookfield, 1981). When referring to self-directed learning, Brookfield initially used the phrase independent adult learning, but subsequently began making a distinction between education and learning (Brookfield, 1984).

Self-Directed Learning

As mentioned, shifting from a dependent role to a self-directed role is a key characteristic of learners as they mature (Knowles, 1980, p. 65). Lindeman (1926), Tough (1979), and Brookfield (1981) also give credence to the role of self-directed learning being key for effective learning for adults. The National Academies of Sciences, Engineering, and Medicine in the 2018 update to *How People Learn* extolled self-directed learning, because the "capacity to understand and direct one's own learning is important not only in school but also throughout life. When learners are self-regulated, they have more control over the strategies and behaviors they use to learn" (National Academies of Sciences, Engineering, and Medicine, 2018, p. 72)

Knowles' (1975b) definition of self-directed learning describes "a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes" (Knowles, 1975b, p. 18). In his *Guide for Learners and Teachers,* Knowles (1975b) suggests that "self-directed learning is more in tune with our natural processes of psychological development" (p. 15) and continues that "an essential aspect of maturing is developing the ability to take increasing responsibility for our own lives – to become increasingly self-directing" (p. 15).

Self-Directed Learning Compared with Self-Regulated Learning

The terms self-directed learning and self-regulated learning are often used interchangeably in literature. The similarities and differences in self-directed learning and self-regulated learning must be noted to establish clarity and appreciation for their use in adult education and how they may vary in other professional fields. The most generally accepted definition of self-directed learning, as quoted above, comes from Knowles. The foundation of self-directed learning is in adult education. Self-regulated learning traces its roots to cognitive psychology. Zimmerman (1990) suggests self-regulation in students can be described based on the degree that they are meta-cognitively, motivationally, and behaviorally active participants in their own learning, and therefore "definitions of students' self-regulated learning involve three features: their use of self-regulated learning strategies, their responsiveness to self-oriented feedback about learning effectiveness, and their interdependent motivational processes" (p. 6).

Saks and Leijen (2014) performed an analysis of how well research articles focused on e-learning published between 2008 to 2012 distinguished between self-directed learning and self-regulated learning. In analyzing 30 articles (12 empirical studies on self-directed learning and 18 empirical studies on self-regulated learning), they found that the sample of articles "showed the tangled use of terms, especially in the articles on self-directed learning…a long list of similar terms - self-management, learner autonomy, independent learning, e-learning - are used synonymously with self-directed learning" (Saks & Leijen, 2014, p. 197). For the purposes of this study, the term self-directed learning (SDL) will be used; however, several studies are referenced in which the term self-regulated learning (SRL) is used interchangeably.

Self-Directed Learning		Self-Regulated Learning
	Similarities 1. Internal and external dimensions: Internal - personality/aptitude External – process/event 2. Four key phases: Define tasks; set goals and plan; enact strategies; monitor and reflect/adjust 3. Active participation 4. Goal-directed behavior 5. Metacognition 6. Intrinsic motivation	
	Differences	
1. originates from adult education; 2. practiced mainly outside traditional school environment; 3. involves designing learning environment; 4. involves planning learning trajectory; 5. broader macro-level construct.		1. originates from cognitive psychology; 2. practiced mainly in school environment; 3. task usually set by teacher; 4. narrower micro-level construct.

Source: Saks and Leijen (2014)

Figure 1. Similarities and Differences Between Self-Directed Learning and Self-Regulated Learning

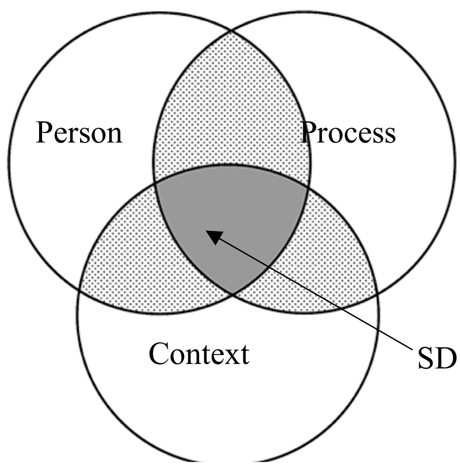
SDL Model: Personal Responsibility Orientation

There are two dimensions to self-directed learning: internal and external. The internal dimension addresses the personality characteristic of the learner, and the external dimension deals with the instructional strategies and environment. Brockett and Hiemstra (1991) recognized that "self-direction in learning refers to both the external characteristics of an instructional process and the internal characteristics of the learner, where the individual assumes primary responsibility for a learning experience" (p. 24). They developed the Personal Responsibility Orientation (PRO) model for self-directed learning (Brockett & Hiemstra, 1991, p. 26).

The PRO model for self-directed learning offered a combination of personality characteristic and instructional methods. The model's use of personal responsibility is a stand-in for personal choice and decision making. Personal responsibility leads to both self-directed learning, which incorporates the characteristics of the teaching and learning transaction, and learner self-direction, which incorporates the characteristics of the learner. Both of these elements lead to self-direction in learning. The entire construct is enveloped in "factors within the social context" since Brockett and Hiemstra suggest it is a myth "that [self-directed] learning takes places in isolation. In order to truly understand the impact of self-direction, both as an instructional method and as a personality characteristic, it is crucial to recognize the social milieu in which such activity transpires" (Brockett & Hiemstra, 1991, p. 32).

SDL Model: Person-Process-Context

In 2012, Hiemstra and Brockett updated the PRO model, advocating instead for a Person-Process-Context (PPC) model for self-directed learning. The update brings clarity to the language used in the PRO model and recognizes a shift in language around the phrase personal responsibility and its political baggage. Hiemstra and Brockett's (2012) PPC model for self-directed learning meshes three characteristics: personal characteristics, such as “creativity, critical reflection, enthusiasm, life experience, life satisfaction, motivation, previous education, resilience, and self-concept” (p. 158); process, which includes the process of teaching and instructional method encompassing “abilities, teaching styles, and technological skills” (p. 158); and context, which clarifies the role of social context including “policies, political milieu, race, and sexual orientation” (p. 158). Figure 2 shows a visual description of the three key characteristics of the PPC model.



Source: Hiemstra & Brockett (2012)

Figure 2. The Person, Process, Context (PPC) Model

SDL Model: Formal, Informal, Nonformal, and Self-Directed Lifelong Learning

The role of the learner in self-directed learning is consistent in literature. As the name implies, the role of the learner in self-directed learning is paramount. Since post-secondary education programs are designed for adult learners, “students entering into these programs without having learned the skills of self-directed inquiry will experience anxiety, frustration, and often failure, and so will their teachers” (Knowles, 1975b, p. 15). Therefore, instructors can play an important role in teaching their students self-directed learning skills through providing opportunities for practice.

One strategy for transitioning from formal learning to self-directed learning is by utilizing what Mocker and Spear (1982) call informal learning. Mocker and Spear present a model for lifelong learning as a two-by-two matrix for the what (objectives) and how (means) of learning. The headers on the matrix are institution and learner. Formal learning is when the institution controls both the objectives and means. Non-formal learning is when the learner controls the objectives, but the institution controls the means. Informal learning is when the institution controls the objectives, but the learner controls the means. Self-directed learning is when the learner controls both the objectives and the means (Mocker & Spear, 1982, p. 4). Figure 3 is a visual description of this matrix. This is a narrower definition for self-directed learning than the generally accepted definition. Nevertheless, informal or non-formal learning can be a bridge to self-directed learning.

Formal learning is "most closely associated with elementary and secondary education and most degree and certificate programs offered by colleges and universities" (Mocker & Spear, 1982, p. 5). Mocker and Spear (1982) contend that "most of the literature from North America dealing with instruction describes informal rather than self-directed learning" (p. 8). Most reasons for using informal learning are "instructor preference, learner preference, and the larger philosophical belief that the individual develops beneficial competencies through the exercise of autonomy and freedom [in learning]" (p. 9).

Transition from Content Transmitter to Facilitator of Learning

Knowles (1975b) identifies steps for instructors to implement self-directed learning. Effective implementation of informal or self-directed learning ensures that both learners and instructors have a clear understanding of the roles and processes. If learners are not equipped with effective strategies to accomplish self-directed learning, "then any decisions or choices the learner makes are likely to be off kilter" (National Academies of Sciences, Engineering, and Medicine, 2018, p. 149).

		What (Objectives)	
		Institution	Learner
How (Means)	Institution	Formal Learning	Nonformal Learning
	Learner	Informal Learning	Self-Directed Learning

Source: Mocker & Spear (1982)

Figure 3. Model for Role of Institution and Learner in Lifelong Learning

The seven steps for instructors to transition from content transmitter to facilitator are described by Knowles (1975b) as:

1. Climate setting – instructors provide learners with a preliminary experience and set the expectations.

2. Planning – instructors share procedures and allow learners to provide feedback.

3. Diagnose needs for learning – instructors construct a model of content objectives and allow the learners to realistically and non-threateningly assess the gaps in the learners' present knowledge and the level required.

4. Setting goals – instructors support the learners to translate needs into clear and feasible learning goals.

5. Designing a learning plan – instructors expose learners to strategies and resources.

6. Engaging in learning activities – instructors assure quality performance in learning activities and serve in a consultative role.

7. Evaluate learning outcomes – instructors enhance learners as self-directed through providing measurement on evidence of accomplishment of objectives (pp. 34–37).

The steps five and six ask the instructor to expose students to learning strategies and resources and to assure quality performance in learning activities. Instructors should guide students in best strategies for learning since "our intuitions and introspections appear to be unreliable as a guide to how we should manage our own learning activities" (Bjork, Dunlosky, & Kornell, 2013, p. 419).

Self-Directed/Self-Regulated Learning and Academic Performance

Students who use more self-directed learning strategies perform better academically. "Successful self-regulated learners have developed the skills and habits to be effective learners, exhibiting effective learning strategies, effort, and persistence" (National Academies of Sciences, Engineering, and Medicine, 2018, p. 73).

Zimmerman and Martinez-Pons (1986) detailed fourteen categories of strategies for self-regulated learning: self-evaluation; organizing and transforming; goal-setting and planning; seeking information; keeping records and monitoring; environmental structuring; self-consequences: rehearsing and memorization; seeking social assistance from peers, teachers, or adults; reviewing tests, notes, or textbooks; and other (p. 618). The authors then interviewed students at a high school in both high-achievement academic tracks and lower achievement tracks to determine how many of the fourteen learning strategies they utilized. The analysis of forty high school students showed that students in the high achievement track reported significantly greater use for 13 of the 14 strategies. Additionally, based on the results, "93% of the students could be correctly classified into their appropriate achievement track through knowledge of their self-regulation practices" (Zimmerman & Pons, 1986, p. 625). Furthermore, "student use of self-regulated learning strategies yielded a substantial increase in prediction of standardized achievement test scores after the effects of gender and socioeconomic status were removed" (Zimmerman & Pons, 1986, p. 625). Further research by Zimmerman (1990) led to his concluding that "all learners are responsive to some degree during instruction; however, students who display initiative, intrinsic motivation, and personal responsibility achieve particular academic success" (p. 14).

Wang, Shannon, and Ross (2013) examined the relationship among students' characteristics, self-regulated learning, technology self-efficacy, and course outcomes in online courses. Based on survey responses from 256 students, the authors were able to conclude that "by using more effective learning strategies, one increases his/her levels of motivation, and the increased levels of motivation toward online courses lead to higher levels of course satisfaction and better performance" (p. 317).

Critical Perspective of Self-Directed Learning

Not all andragogy researchers are convinced that self-directed learning is a vital component of adult education. Mezirow (1985) suggested:

> The learner cannot know what his or her learning needs are when he or she does not know what is required to become a machinist, build a bridge, or perform a root canal operation. The same thing is true when the subject matter to be learned is hierarchical and observes an ordered progression, as in the. case of algebra, where beginning algebra precedes advanced algebra. A learner would know his or her learning needs if he or she

> could know what he or she could want. Obviously, there are many areas of learning where self-directedness as Knowles defines it does not apply. (p. 26)

One reason Mezirow may have been critical of self-directed learning is because his theory and definition of adult education requires an interaction between the instructor and learner. Mezirow's transformative learning theory requires a disorienting dilemma that changes the learner's frame of reference, and if there was transition in the role of the instructor from content transmitter to facilitator, there would be a risk of no disorienting dilemma. Mezirow (1985) suggested "there is probably no such thing as a self-directed learner" (p. 27).

Brookfield (1984) identified that an advantage of the research into self-directed learning was that it "challenged the assumption that adult learning can only occur in the presence of a fully accredited and certified professional teacher appropriately trained in techniques of instructional design and classroom management" (p. 60). Additionally, Brookfield suggested that as a result of research into self-directed learning, it was hard to ignore learning in non-institutional settings which was typically "held to be serendipitous, ineffective and wholly experiential" (Brookfield, 1984, p. 60). Brookfield (1984) then levels four criticisms against self-directed learning:

> (1) the emphasis on middle class adults as the sampling frame for studies of this mode of learning, (2) the almost exclusive use of quantitative or quasi-quantitative measures in assessing the extent of learning and the concomitant lack of attention to its quality, (3) the emphasis on the individual dimensions of such learning to the exclusion of any consideration of the social context in which it occurs and, finally, (4) to the absence of any extended discussion of the considerable implications raised by these studies for questions of social and political change. (p. 60)

Since Brookfield shared his criticisms in 1984, subsequent researchers were able to address some of these critical views. For example, Brockett and Hiemstra's PRO Model (1991) for self-directed learning and its updated PPC Model (2012) both address the social context in which self-directed learning occurs.

Knowledge Retention

While this study is not strictly a study on knowledge retention, it must be noted that the adoption of the self-directed primer e-book was conceived as a way to address the observational experiences an instructor had with students' weaker understanding of concepts learned in the first course of a two-course sequence. As such, a review of knowledge retention studies and the impact of knowledge retention on academic performance is warranted and beneficial.

Knowledge Retention and Decay

Hermann Ebbinghaus, a 19th century German psychologist, is credited with pioneering the study of memory and knowledge retention. Ebbinghaus started laboratory experiments for measuring knowledge retention by investigating his ability to recall nonsense syllables after retention intervals of different lengths. Based on his consistent results, he shared what came to be known as the "Ebbinghaus curve of forgetting" (Ebbinghaus, 1966, as cited in Custers, 2010). The Ebbinghaus curve of forgetting revealed large losses at short intervals, and a levelling off with smaller incremental losses at longer intervals.

With regard to memory and retention for learning, the review of studies by Bjork, Dunlosky, and Kornell (2013) strongly recommend that institutions are wrong to "assume that children and adults do not need to be taught how to manage their learning activities" (Bjork et al., 2013, p. 419). The authors shared information about how to become a sophisticated learner – one who learns effectively:

> (a) understanding key aspects of the functional architecture that characterizes human learning and memory, (b) knowing activities and techniques that enhance the storage and subsequent retrieval of to-be-learned information and procedures, (c) knowing how to monitor the state of one's learning and to control one's learning activities in response to such monitoring, and (d) understanding certain biases that can impair judgments of whether learning that will support later recall and transfer has been achieved (Bjork et al., 2013, p. 419).

Key aspects of the functional architecture that characterizes human learning and memory deals with how the brain encodes and retrieves information. Human brains do not record things exactly and play them back like a recorder. Humans learn by connecting existing knowledge to prior knowledge. Counterintuitively, the brain does not run out of space when we learn, but storing additional information creates capacity (Bjork et al., 2013, p. 420). Retrieving information "is considerably more potent (as a learning event) than is an additional opportunity, particularly in terms of facilitating long-term recall" (Bjork et al., 2013, p. 420), but it can cause retrieval-induced forgetting of competing information stored with the same recall cue. Learners must also be active in their learning and not passive; practicing the retrieval process is critical. The example provided is related to safety in an airplane:

> Allowing passengers one chance to actually put on, fasten, and inflate an inflatable life vest would be of more value—in terms of the likelihood that one could actually perform that procedure correctly in an emergency—than the multitude of times any frequent flier

has sat on an airplane and been shown the process by a flight attendant (Bjork et al., 2013, p. 420)

Bjork et al. (2013) showed students make critical mistakes in learning strategies. Learners must engage in activities that store new information and connect it with other concepts. This means organizing learned knowledge, leveraging technologies that enhance learning, and collaborating to exercise encoding and retrieval of information. Learners should take control of their own learning activities and determine that they should space rather than mass study sessions, interleave to-be-learned concepts rather than block them within successive sessions. Although it seems counterintuitive, learners should also vary their environment rather than keeping conditions consistent and predictable. Additionally, learners should use self-test techniques to generate information or procedures rather than just looking up the answer. Bjork et al. (2013) conclude that "becoming sophisticated as a learner requires knowing how to manage one's own learning activities" (Bjork et al., 2013, p. 421).

Science and Organic Chemistry Knowledge Retention

Using effective learning strategies with organic chemistry becomes important because organic chemistry is a conceptual subject and not prone to rewarding students who rely solely on memorization or generated algorithms for learning (Raker & Holme, 2013; Raker & Towns, 2010). A review of standardized organic chemistry exams over the years offers insight into the changes in curriculum and teaching and assessment techniques. An analysis by Raker and Holme (2013) found that "conceptual questions account for 90% or more of the test items that appear on the 2012 ACS standardized Organic Chemistry Exams" (p. 1439), while about 5% of the questions are algorithmic problems. Recall problems comprised 40% of the examinations analyzed from 1949 but have declined to less than 5% of the exams analyzed from 2012. The assessment topics also provide valuable insight into topics that can be covered in the primer e-book. Raker and Holme (2013) find that “content topics begin with an introduction to molecular structure and properties (such as acidity and boiling point); simple reactions of alkanes, alkenes, and alkynes; substitution and elimination reactions; spectroscopy; carbonyl chemistry; and conclude with nitrogen-containing compounds and an introduction to biochemistry” (p. 1438).

Custers (2010) performed a meta-analysis of studies that investigate how well basic science knowledge is retained by those going on to medical school and becoming medical doctors. To measure knowledge retention, studies measure knowledge decay or knowledge attrition, defined as how students retain or forget concepts they have previously learned. There are different means of measuring knowledge attrition: “cued recall (i.e., open-ended questions), recognition (i.e., true-false questions), or multiple choice questions that draw upon both recall and recognition” (Custers, 2010, p. 111). His summary of educational classroom studies and naturalistic long-term studies concluded that “knowledge should be acquired over an extended period in a cycle of repeated re-learnings or rehearsals. That is, the number of courses an individual has taken in a particular subject is a much more important determinant of knowledge maintenance than a high grade received in a single course though course grades predict retention test performances on the short term relatively well” (Custers, 2010, p. 118). With regard to specific retrieval intervals, Custers (2010) concluded that the “evidence is consistent with the rule of thumb that after a retention interval of one year, approximately one-third of the knowledge gain is lost, accumulating to slightly over one-half after a few years” (p. 123).

Blizard, Carmody, and Holland (1975) investigated retention of physics and chemistry knowledge among medical school students, concluding “that students do not seem to retain much knowledge of the basic definitions or formulae of physics and chemistry at intervals of either 4 or 16 months after completion of their basic science courses" (p. 250). For chemistry, the authors used two groups of students: 143 second-year medical students who would have completed the basic chemistry course four months prior and 166 third year students who would have completed the basic chemistry course sixteen months prior. Students were administered a 17-item test composed of recall, minimal application, and recall with major application for physics and chemistry information taught during the first-year basic courses. For the second-year students on the chemistry portion, 92.9% of the students demonstrated greater than 50% proficiency on the exam at the end of the course, but only 34.1% demonstrated a greater than 50% proficiency at the 4-month follow-up. For third-year students on chemistry knowledge, 94.5% demonstrated a greater than 50% proficiency at the end of the course, but only 29.7% demonstrated a greater than 50% proficiency at the sixteen-month follow-up. The authors attribute the results to two reasons: "students fail to understand the importance or significance of physics and chemistry to their future studies, and the methods used to teach physics and chemistry lead only to very short-term retention of what has been learned and very little in the way of long-term retention and understanding" (Blizard et al., 1975, p. 252).

Saffran, Kennedy, and Kelly (1981) utilized the National Board of Medical Examinations to measure biochemistry retention over 22-months by the same test takers. Approximately 2,600 students took Part I of the examination in June 1975 and Part II of the examination in April 1977. "Part I is usually taken at the end of the second year of medical school and consists of approximately 1000 multiple-choice questions" (Saffran et al., 1981, p. 97) and "Part II, usually taken during the fourth year of medical school, consists of approximately 900 multiple-choice questions" (Saffran et al., 1981, p. 97). Saffran inserted the same 35 biochemistry questions in both Part I and Part II of the examination. In 1975, the average score amongst the Part I test takers on these 35-questions was 65.6% correct. In 1977, the same 2,600 test takers on Part II of the examination answered only 51.6% of the same 35-questions correctly – a decline of 14%. With regard to individual questions, performance between the two years improved on four questions, remained the same on one question, and declined on thirty questions. Of the seven basic science disciplines and six clinical disciplines covered by the board examinations, "biochemistry suffered the greatest decline in performance" (Saffran et al., 1981, p. 98) and was identified as "the least well retained of the basic sciences" (Saffran et al., 1981, p. 98). Saffran et al. (1981) concluded that it is up to the faculty to decide whether they are satisfied with the level of retention demonstrated by their students, and if they are not, the faculty should consider what they offer that is worth remembering and reinforce that content in successive courses. The reason the results above are relevant to this study is that organic chemistry is a prerequisite course for biochemistry in most universities: "The vast majority of U.S. colleges and universities still teach chemistry in a more-or-less standard approach: one year of general chemistry, one year of organic chemistry, and one year of physical chemistry, in that order…and due to requirements from the ACS Committee on Professional Training, a biochemistry course, of probably one-semester in the junior year" (Reingold, 2004, p. 470).

Interventions to Improve Organic Chemistry Academic Success

The knowledge retention studies mentioned demonstrate that students struggle with retention of chemistry knowledge more than in other sciences. Perhaps in recognition of this, chemistry education researchers have attempted several interventions or modifications to support knowledge transfer and retention in courses. The following is a brief review of different instructional strategies and techniques.

In-Person Bootcamps

A boot camp in the context of learning is a preparatory course, usually offered during an intersession period. Generally, the phrase boot camp is borrowed from the military parlance to describe an “intense experience that lays a strong foundation for success in upcoming engagements” (Siebert, Daniel, & High, 2017, p. 1860). Siebert et al. (2017) offered a one-credit hour “Preparing for Organic Chemistry” boot camp course to students at Missouri State University in the intersession period prior to their enrollment in OC1. The course was open to students who had enrolled in OC1 and had completed General Chemistry II with a grade of C- or better. The one-credit-hour course charged students tuition and fees. The course met every weekday from 9 a.m. to 12:30 p.m. in the week immediately preceding the start of Fall 2014 and Fall 2015 terms. The topics were identified by the authors based on experience teaching OC1 and the general chemistry review topics that usually appear at the beginning of organic chemistry textbooks.

In 2014, Siebert et al. (2017) observed no statistically significant relationship between completion of the boot camp course and success in OC1 (a grade of C- or better). In 2015, however, 88.9% of the students who completed the boot camp attained a grade of C- or better in OC1, while only 74.1% of students who did not complete the boot camp achieved the same. This difference between 2014 and 2015 results was attributed to modifications in content and emphasis made during the boot camp course. It is worth noting, however, that likely due to the tuition and fees for the course, only 28% of students enrolled in OC1 participated in the boot camp course, and the average cumulative GPA of the students who participated was higher than the overall course average cumulative GPA.

Communicative Implementation of Bloom's Taxonomy

Pungente and Badger (2003) suggested academic performance issues in organic chemistry were a result of a disconnection between the category or classification on Bloom's taxonomy that the instructor teaches and assesses, and the classification on Bloom's taxonomy that students perform their learning activity. Bloom et al. (1956) broke down the cognitive learning domain into six hierarchical categories, from simple and concrete to more complex and abstract. Increasing in complexity, the categories are Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation (pp. 201–207). Although the taxonomy was updated in 2001, Pungente and Badger used the 1956 version of the taxonomy. The challenges Pungente and Badger (2003) identify are that "too often when the instructor kicks into higher-level cognitive gear and begins delving into applications, the students are still functioning at the lower knowledge and comprehension cognitive levels, memorizing seemingly unrelated facts" (p. 780). With assessment, this disconnection becomes obvious when, perhaps unknowingly, the instructor teaches at a lower cognitive level, but assesses at a higher cognitive level. Pungente, in his effort to have students understand the material rather than memorize it, introduced his introductory organic chemistry course to Bloom's taxonomy, and often made references to which cognitive level they should process the lecture material he presented. Pungente and Badger (2003) concluded "students' learning is profound once they begin to view organic reactions and interactions from a basis of understanding rather than as a collection of unrelated facts that they must memorize for the exam" (p. 782).

Online Learning

As textbook publishers and other vendors have started providing online homework companion platforms, there have been more studies on the efficacy of incorporating these platforms into organic chemistry instruction. The initial study at West Virginia University of the implementation of the Web-based Enhanced Learning Evaluation And Resource Network ("WE_LEARN") showed conclusions that a positive change occurred in the classroom as "in comparison to previous years, students obtained higher test scores and were more confident when taking exams" (Penn, Nedeff, & Gozdzik, 2000, p. 230).

Fifteen years after the initial study, West Virginia University researchers Richards-Babb, Curtis, Georgieva, and Penn (2015) published the student perceptions of online homework used for formative assessment while learning organic chemistry in two course sections with a total of 159 of 226 students participating in the survey. Overall, "students expressed relatively positive attitudes toward online homework use in organic chemistry" (Richards-Babb et al., 2015, p. 1815) with an average overall score of 3.85 on a 5-point Likert scale. The courses used the WileyPlus platform.

Within the data, the more interesting finding is that of the two sections that participated in this study, 90.4% of the students in section A responded that the online homework was a useful course activity, while only 38.1% of section B students responded similarly. Students in section B assigned a higher rating to the optional chapter problem sets (47.6%). This discrepancy can be attributed to the fact that the exams in section A are computer-based similar to the online homework, and exams in section B were paper-based similar to the optional assignments (Richards-Babb et al., 2015, p. 1816). This reveals that while students had an overall positive impression of the online homework, they placed a higher value on practice that most resembled the exams.

Parker and Loudon (2013) implemented the Sapling Learning online homework platform in the College of Pharmacy at Purdue University with organic chemistry students in prepharmacy. The online homework was offered for extra credit for two of four course sections, with a maximum possibility of adding approximately 5% to the final grade. With regard to the online homework platform, the authors concluded that students who were more engaged with the platform had improved performance. The more interesting findings related to engagement with the system based on the offering of extra credit. Of the four course sections using the online homework platform, extra credit was offered in only two of them. According to the survey administered to students, "33% of students reported that they would definitely use the system regardless of extra credit point incentive obtained" (Parker & Loudon, 2013, p. 42). Based on the data gathered from actual student registration, and completion of substantial assignments, in the two sections for which extra credit was offered, 97% and 92% of students registered for the online homework system, and 88% and 83%, respectively, completed a substantial number of assignments. For the two sections for which extra credit was not offered, 88% and 24% of students registered for the system, and 64% and 3% of the students completed a substantial number of assignments. The conclusion, thus, is that these "data indicate that the extra credit point incentive itself is critical to engaging students in the use of an [online homework platform], regardless of their previous positive experiences with the same system" (Parker & Loudon, 2013, p. 43).

Fischer, Zhou, Rodriguez, Warchauer, and King (2019), chemistry education researchers at the University of California at Irvine (UCI), designed a three-week online organic chemistry preparatory course with the goal of improving student academic performance in OC1. The authors used the online preparatory course to identify characteristics of students who participate in the course, the effect of participation in the preparatory course on the subsequent organic chemistry course, and the effect of participation in the course for low-income students, first-generation students, and underrepresented minorities. The course was designed using the Sapling Learning system and delivered via Canvas learning management system. The content was comprised of a custom e-book and 16 lecture-style videos. The course was optional, with a fee of approximately $28. Accounting for various characteristics, “students who participated in the online preparatory course performed on average about one-third of a letter grade (e.g., C+ to B−) better in the subsequent organic chemistry course compared to students who did not participate in the online preparatory course” (Fischer et al., 2019, p. 861). Since the course was optional, Fischer et al. found that female students were more likely to participate, and academic preparation, high school GPA, and college credit awarded at time of admission were reliable indicators of participation. At-risk student populations, which includes low-income students, first-generation students, and underrepresented minorities, saw similar results of a one-third letter grade increase for students who participated in the preparatory course.

Active Learning

Active learning is defined as any instructional method that engages students in the learning process through learning activities in the classroom that have the student think about what they are doing (Bonwell & Eison, 1991). Examples of classroom techniques utilizing active learning include problem-based learning and collaborative learning, which contrasts with lecture-based content dissemination. Crimmins and Midkiff (2017) converted one section of a large lecture organic chemistry course and examined student performance data over four years. The result of the analysis found “high structure active learning is a powerful method for improving student academic outcomes in Organic Chemistry” (Crimmins & Midkiff, 2017, p. 436). Compelling in their findings was that “those students in the 50th and 25th percentiles benefitted the most, on total points earned, final exam grade, and the likelihood of earning a higher final grade" (Crimmins & Midkiff, 2017, p. 434).

Curricular Changes

Collins-Webb et al. (2016) recognize the weeder course reputation of organic chemistry and attribute it to the "progression from quantitatively-oriented general chemistry to a typically mechanisms-oriented organic chemistry" (p. 26), proposing the solution that "elements of organic chemistry can be introduced as part of the general chemistry curriculum" (p. 26).

Instead of academic performance data, Collins-Webb et al. (2016) used an open-ended survey to gather feedback from students after they completed or were enrolled in organic chemistry. A control group of students completed the general chemistry course that did not incorporate organic chemistry elements, and the experimental group had completed a general chemistry course with introductory content from organic chemistry.

Collins-Webb et al. (2016) identified four key findings from the survey results: (1) the experimental group "reported less frequently that there was no application of concepts between general and organic chemistry (4.5% v. 19.8% $p \leq 0.001$)" (p. 28); (2) approximately half of the experimental group "indicated that the organic unit was significant in preparing them for organic chemistry (51.0% v. 2.3%, $p \leq 0.001$)" (p. 28); (3) the experimental group reported "significantly more frequently that they were not concerned about the transition to organic chemistry (15.1% v. 7.4%, $p \leq 0.001$)" (p. 28); and (4) the experimental group was "significantly less concerned about the less quantitative nature of organic chemistry (4.5% v. 8.1%, $p \leq 0.05$)" (p. 28). Some of these results can be attributed to the nature of the experimental group. For example, it makes sense that students in an experimental group would indicate that the organic unit called Introduction to Organic Chemistry would be significant in preparing them for the next course. Data from academic performance in the organic chemistry course would have been valuable in addition to the survey data.

Schnoebelen (2018) describes the curricular changes at Purdue University's Department of Chemistry in coordination with the National Experiment in Undergraduate Science Education (NEXUS) collaborative project by the Howard Hughes Medical Institute. The impetus for change at Purdue was not academic performance of students in organic chemistry, but "belief by the faculty members involved in the project that the existing chemistry courses did not meet the needs of life-science students" (Schnoebelen, 2018, p. 2). Faculty at Purdue changed the curriculum from a one year/two-course general chemistry sequence to a one-semester/one-course general chemistry component. Students went from two 4-credit hour general chemistry courses to one 5-credit hour course, followed by a two-course/one-year organic chemistry sequence and a one-term biochemistry course. This curriculum, described as 1-2-1, was specifically used for students interested in the life sciences. With regard to performance in OC1, students in the 1-2-1 curriculum "performed just as well as, or slightly better than, their traditional peers, with a greater percentage earning an A, a greater percentage earning an A or B, and a smaller percentage earning a D or F" (Schnoebelen, 2018, p. 68). There were also similar results on exam scores.

Flipped Classroom Learning

Flipping the classroom, also known as blended learning, is an instructional delivery strategy in which "students gain first exposure to new material outside of class, usually via reading or lecture videos, and then use class time to do the harder work of assimilating that knowledge, perhaps through problem-solving" (Brame, 2013) and other similar in-class activities that may be collaborative or team-based.

Shattuck (2016) explored the impact on student performance, perception, and course completion by partially flipping one of the two course sections of OC1 he was teaching. The total course enrollment in each course was n=26, which is less than one-fifth of the typical large-lecture type delivery of OC1 at most universities. Shattuck (2016) observed that “although final exam grades and overall course averages were very similar, the flipped section earned 25% more course grades of A and B than the control. In addition, the withdrawal rate was 54% lower in the flipped section” (p. 1991).

Summary of Interventions in Organic Chemistry

The selection of instructional strategies discussed include in-person bootcamps, better utilization of Bloom's taxonomy, online homework portals or preparatory classes, curricular changes, or flipped learning. It is worth noting that while all these studies discuss organic chemistry, they are all primarily concerned with the transition from general chemistry to OC1 in the curriculum. Yet the details in much of their data revealed attrition between courses.

E-Books

This study uses a self-directed primer e-book to support a learner’s transition from OC1 to OC2. The terms electronic book and e-book were first used by Andries van Dam, founder of the Hypertext Editing system and the File Retrieval and Editing SyStem (FRESS) at Brown University in 1968. The concept of an e-book, or an “electronic file that contains the complete text of a book that was initially published, or could have been published, in the usual printed form” (Reilly, 2003, p. 85), was expanded by Michael Hart in 1971 when he obtained significant computing time on a Xerox Sigma V mainframe at the University of Illinois and used this time to begin digitizing books and launching Project Gutenberg, the first provider of free e-books with the mission “to encourage the creation and distribution of eBooks” (“About Project Gutenberg,” 2019). As of July 2019, Project Gutenberg has over 59,000 e-books available free.

E-Textbooks

While the technology for e-books has been around for decades, it took until the 2010s for the consumer use of e-books to grow with the release of the Amazon Kindle in 2007, followed by the Apple iPad in 2010. According to the 2010 *Horizon Report*, an annual publication that discusses trends in education technology, “this ready availability of a selection of capable readers is one of the factors contributing to the success of electronic books” (Johnson, Levine, Smith, & Stone, 2010, p. 17). Even with the growth in consumer e-books, academia has been slower to adopt e-books as textbooks. The 2010 *Horizon Report* indicated that this was largely due to three factors: limited availability of titles, limited capability of reader technology, and the fact that publishers made e-books available largely as ancillary items to printed text in order to preserve their business model (Johnson et al., 2010, p. 18). In 2009, Indiana University piloted its eText Initiative, a partnership with publishers to purchase e-book textbooks in bulk and make them available to students automatically on the first day of class at a reduced cost (Straumsheim, 2016).

Use of paper-based textbooks continues to negatively impact academic performance. A survey of 22,000 public higher education students in the State of Florida revealed that: (1) 67% of the survey respondents did not purchase the required textbook; and (2) 48% of the students occasionally or frequently took fewer courses than desired, while 26% dropped a course and 20.7% withdrew from a course due to the high cost of textbooks (Florida Virtual Campus, 2016, pp. 5–6).

While e-book usage to replace textbooks is growing, print textbooks are still widely adopted as the most common format. Muir and Hawes (2013) suggested that "if e-books are to be widely adopted as an alternative to the printed book for academic work, then they must provide a better user experience and tangible enhancements for scholarly work" (p. 261). E-books typically add enhancements and functionality such as search tools, bookmarks, ability to highlight and annotate, multimedia features such as videos, and instant access via the Internet. Muir and Hawes (2013) added that "features e-books offer (as enhancements to printed book content) are only as beneficial as the user's ability to grasp and use them in an intuitive and user-friendly way" (p. 261). The authors used an observation case study approach and first administered questionnaires to 63 students in a quantum mechanics course that used e-books. Based on that questionnaire, the authors obtained over 14 hours of observed tasks and interviews of 14 randomly selected users. Muir and Hawes (2013) concluded that "current approaches to training students to use e-books effectively for scholarly activity is generally lacking" (p. 272) and that it was relevant for "academic instruction to develop the necessary e-book literacy skills to achieve effective use of academic e-books" (p. 272).

Despite the need for students to learn how to effectively use e-books for learning, most studies show students prefer e-books. Sharing the student academic usage preferences of a Kindle pilot at a college, Martinez-Estrada and Conaway (2012) found that "Sixty-six students (75%) reported their experience was better, one fifth were indifferent (23%), and 2% reported the Kindle experience made it worse. Ninety-four percent said they would recommend use of the Kindle to other students, and 72% of the students preferred the e-book version" (p. 131). Student satisfaction studies consistently found a preference for e-books for academic use when compared with paper-based textbooks (Carroll et al., 2016; Chelin et al., 2009; Shelburne, 2009).

E-Textbooks in Organic Chemistry

The American Chemical Society (ACS) launched an e-book program in July 2009 through its Publications Division. The online collection started with over 1,200 ACS books published between 1950 to 2009 (American Chemical Society, 2009). A search on Academic Search Premier, ERIC, ACS Publications, and Google Scholar using the keywords "etext," "ebook," "etextbook," or "electronic book" and the phrase "organic chemistry" since the year 2009 and limited to the United States displayed two relevant results (Fischer et al., 2019; Franco & Provencher, 2019) that are discussed in this literature review. Fischer et al. (2019) appeared in the search results even though it is primarily about an online preparatory course because the instructors also used an e-book. The study is reviewed under the online learning heading of this chapter.

Franco and Provencher (2019) took advantage of being at a school that had an Apple iPad initiative that supplied the tablet device to each student. The authors created an e-book using the iBooks Author program. E-books created with iBooks Author are supported only on the Apple Macintosh or iOS platform, meaning users with Windows-based PCs or Android OS tablets and devices are not be able to open a fully functional iBooks Author e-book. The e-book allowed users to "highlight text, create notes and study cards, and search the text, in addition to using all of the embedded text, videos, figures and quizzes" (Franco & Provencher, 2019, p. 587). The published article does not contain any information on the population sample size. Based on the student survey responses, 80.3% of the unknown number of students responded yes when asked if the e-book helped them more effectively learn the course material. The response options were Yes, No, or Not Sure. Additionally, 71% of the students surveyed preferred the e-book to a traditional textbook. No academic performance data were provided; therefore, it is not possible to determine if using the e-book for this course enhanced student academic performance.

Learner Characteristics and Academic Performance

Since this study is measuring the impact on academic performance based on a selection of learner characteristics, namely gender, race, admission type, cumulative GPA, standardized test scores, academic major, and grade in the first course of a course sequence, it is necessary to review the existing literature on how these learner characteristics impact academic success. Where available, studies relating to academic performance relating to science courses, generally, or organic chemistry, specifically, are reviewed.

In most of the studies reviewed in this chapter, academic performance or academic success refers to course grades and test scores at the course level, or persistence and graduation at the program or institution level. Particularly for STEM classes, the use of student grades makes sense because "the grade received in a course is an important factor in the decision to continue studying the subject" (Rask, 2010, p. 894), meaning it leads to persistence.

Academic Performance Based on Gender

Females consistently made up 56% or greater of all undergraduate enrolled students at colleges and universities in the United States each year between 2012 and 2016 (National Science Foundation, National Center for Science and Engineering Statistics, 2019), yet in 2016 only 35.5% of all STEM-field graduates in the United States were female (National Center for Education Statistics, 2019a). Studies consistently show that female students earn higher undergraduate GPAs than male students. Buchmann and DiPrete (2006) studied the role of family background and academic achievement to explain gender disparities in higher education, and found "female advantage over males is largely attributable to the superior performance of women in college" (p. 532). Tai and Sadler (2001) studied student performance in introductory physics courses at 16 universities, and even though there were "more than twice as many males than females with high school physics experience in the surveyed courses" (p. 1027) females still earned a higher grade in the college-level physics courses. In a qualitative study of why females majoring in science, engineering, or mathematics switched to non-science based majors, Seymour (1995) found that 83.9% of females (compared with 68.5% males) cited lack of help with academic problems as a factor, and 37% of females (compared with 32% of males) indicated lost confidence due to low grades in early years as a factor for switching majors (p. 444), highlighting the "differential impact of the weed-out system on men and women" (p. 447).

Focusing on organic chemistry, Turner and Lindsay (2003) used two cohorts with a total of 193 students to determine which cognitive and non-cognitive characteristics can be used to predict success in an organic chemistry course and if certain of those characteristics exhibit a stronger correlation for females than males. For both cohorts, a stepwise multiple regression analysis of all variables revealed that the second semester general chemistry grade and ACT math grade "accounted for the largest percentage of variance associated with organic chemistry achievement" (Turner & Lindsay, 2003, p. 565), but "each predictor variable accounted for more variance among men than among women" (Turner & Lindsay, 2003, p. 567).

In a study of academic intervention for chemistry courses, Richards-Babb and Jackson (2011) measured the impact of using online homework on general chemistry courses over nine years. In comparing course sections prior to online homework with sections using online homework, the authors found "average success rate of female students in general chemistry significantly improved by 5.0%" (Richards-Babb & Jackson, 2011, p. 413) and performance for male students increased 10.1%. While the online homework did not negatively affect female students, there was a disparity by gender. "Without online homework (pre-fall 2006), female students were 6.9% more likely to earn final letter grades of A, B, or C than their male counterparts" (Richards-Babb & Jackson, 2011, p. 413) an achievement gap that decreased to a 1.7% advantage for females after the utilization of the online homework.

While studies show female students perform better academically, any intervention should measure gendered outcomes to ensure there is no negative effect.

Academic Performance Based on Race

In 2000, non-white children between the ages of 0-17 made up 39% of the United States population, and in 2018 the proportion increased to 49.3% (Federal Interagency Forum on Child and Family Statistics, 2018). Between 2006 and 2016, the share of non-white students enrolled as undergraduates in 4-year institutions in the United States has increased from 38% to 47.3% (National Science Foundation, National Center for Science and Engineering Statistics, 2019). The number of non-white students earning a bachelor's degree in a STEM field nearly doubled from 76,554 (31.5% of all students) in 2008-09 to 140,681 (61.5% of all students) in 2015-16 (National Center for Education Statistics, 2019a). It is worth noting the trend in STEM majors and graduates since organic chemistry is usually a required course for that population of students. The trends clearly indicate that racial stratification at colleges and universities is becoming more heterogenous.

Despite serving a growing diverse population of students, the academic performance metrics for minority student groups continue to be lower than their white counterparts. Kao and Thompson (2003) found that non-white and non-Asian minority groups get significantly lower grades despite similar education attainment goals (p. 435). Buchman and DiPrete (2006) found that "blacks get significantly lower grades in college" (p. 532). Grades have a significant impact on persistence, as Nora et al. (1996) found for minorities at 4-year institutions that an "increase of one grade point increased the likelihood of persisting by 9.46%" (p. 444). Often race and socioeconomic status get conflated in studies, but MacPhee et al. (2013) found for minority students from low socioeconomic status when only one of those two characteristics was present resulted in significantly lower "(i) academic self-efficacy, (ii) test taking skills; and (iii) academic performance as indicated by GRE and critical thinking scores as well as cumulative GPA, with effect sizes between .43 (moderate) and .62 (large)" (p. 365).

When reviewing demographic-based academic results based on race, it is important to acknowledge that for the purposes of statistics, broad racial groups are created, such as Asian, but within these groups there can be significant disparities that negate the perception that equal opportunity and equal outcomes apply to the entire group. For example, while studies show that Asians have higher academic outcomes, "only 35% of Cambodian foreign-born adults (aged 25 or over) have a high school diploma, and only 5% have a 4-year college degree; similarly, 37% of foreign-born Laotians have a high school diploma, and only 4.6% have a 4-year college degree" (Kao & Thompson, 2003, p. 432).

Determining the causes of racial disparity in academic performance is outside the scope of this study. However, measuring the effect of utilizing the primer e-book as an intervention in organic chemistry by race may identify ways of supporting populations for whom grades have a larger impact on persistence.

Transfer Student Academic Performance

Of the 2.8 million college students who started their post-secondary academic journey in Fall 2011, 40.8% began at a two-year public institution (community college), compared with 37.6% who started at a public four-year institution (Shapiro et al., 2018, p. 7). The six-year transfer rate for the Fall 2011 cohort was 36.7% (Shapiro et al., 2018, p. 12), meaning a little more than one in three students starting at a community college transferred to a four-year institution. The six-year bachelor's degree graduation rate (six years from start at 2-year institution) for transfer students was 42% compared with 60% for students who started at a 4-year institution (Shapiro et al., 2017).

Glass and Harrington (2002) studied the phenomenon of transfer shock – lower GPA by transfer students after they arrive at their new institution – of students in the state of North Carolina and found that while there was no significant difference in GPAs of both community college students and students at four-year institutions at the end of two years, "mean semester GPA (2.59) for transfer students at the end of fall 1996 was significantly lower than the mean GPA (2.98) of the native students at the end of their first semester in the major" (p. 421). The study revealed that at graduation time, there was either no significant difference in GPAs of transfer and native students (Spring 1998 cohort), or the transfer GPA was 0.29-points higher than native graduates (Spring 1999 cohort), a significant difference (Glass & Harrington, 2002, p. 423). If students transfer to an institution and enroll in OC2 during their first term, they are more likely to earn a lower grade as a result of experiencing transfer shock.

Whitfield (2005) studied the grades earned by transfer students versus native students over four years in upper level organic chemistry and biochemistry courses where transfer students took an entire year of prerequisite courses at another institution. Transfer students had a higher mean grade in the prerequisite courses, and their grade in organic chemistry was 0.11 grade points lower than native students. While this was a significant difference, "transfer students compared reasonably well to their university counterparts in organic chemistry" (Whitfield, 2005, p. 536). For biochemistry, transfer students in the study completed the prerequisite organic chemistry course at a community college. Grades in biochemistry for transfer students were 0.20 grade points lower than native students. Additionally, while transfer students in the Glass and Harrington (2002) study recovered their GPA by graduation, Whitfield (2005) found that the "important and indisputable result is that the gap - what might be called the transfer achievement gap - between the native and transfer students did not decline as students spent more time in the university environment" (Whitfield, 2005, p. 538).

Cumulative GPA as a Predictor of Academic Performance in Organic Chemistry

The cumulative grade point average is the quality points earned in all college coursework divided by the total number of credit hours attempted. The cumulative grade point average does not remove quality points if a student re-takes a course. Brookshire and Palocsay (2005) were interested in predicting the course grade of students in a management sciences class that is a challenging undergraduate course in the business curriculum. The authors analyzed the cumulative GPA, math SAT score, calculus grade, and statistics grade and found all four have significant bivariate correlations with the grade in management sciences; however, when the variables were "combined into a predictive model, the GPA stands out as clearly the most important indicator of management sciences success" (Brookshire & Palocsay, 2005, p. 104). Brookshire and Palocsay (2005) calculated that the "R^2 value for GPA, controlling for major and instructor, was .537. Adding the other three variables increases the R^2 by only an additional .02" (p. 104).This study confirms that it is possible to have courses for which cumulative GPA is a strong predictor of success.

Wright, Cotner, and Winkel (2009) studied the correlation, if any, between the prerequisite organic chemistry course and biochemistry. While they did not find a strong correlation between the prerequisite course and biochemistry, they did determine that "other than the similar relationship between average semester grade and the [biochemistry] grade, [the cumulative GPA] relationship was the only strong correlation, positive or negative, that we uncovered in our pairwise analyses of all factors in this study, including transfer credits, total credits, grade in General Chemistry 1 and 2, organic chemistry lecture, college of enrollment, or major" (Wright et al., 2009, p. 50).

Szu et al. (2011) examined how prior academic performance impacts academic outcomes in organic chemistry and determined that "prior GPA was positively correlated with final course grade" (p. 1240). More importantly, for implications for studies in cognitive intervention, the authors also concluded that when "study behaviors and concept map scores were combined in a regression equation, addition of prior GPA accounted for no significant additional variance" (Szu et al., 2011, p. 1240), meaning students at risk of poor organic chemistry performance due to prior academic performance can overcome a bad grade through good study behaviors.

Standardized Test Scores as a Predictor of Academic Performance

There are two common standardized tests that assess readiness for college and are used for admissions at U.S. post-secondary institutions. The SAT, offered by the non-profit College Board, started in 1926 by the name of Scholastic Aptitude Test. The SAT is comprised of two sections, critical reading and mathematics, each with scores scaling from 200 to 800. A combined SAT score ranges from 400 to 1600. In 2016-2017, students in the 25th percentile of SAT starting at 4-year institutions had a critical reading score of 469 and a mathematics score of 475; students in the 75th percentile of SAT had a critical reading score of 578 and a mathematics score of 584 (National Center for Education Statistics, 2017). Ewing et al. (2005) reported that "with the exception of the writing skills, most skills exhibited acceptable internal consistency and alternate-form reliability estimates" (p. 7).

The American College Test, or ACT, has been administered by the non-profit ACT since it started in 1959. The ACT examines four academic subject areas: English, mathematics, science reasoning, and reading. Each of the four subject areas is graded on a scale of 1 to 36, and the composite score is the rounded average of the four subject scores. In 2016-2017, students starting at 4-year institutions with scores in the 25th percentile of the ACT had an English score of 19.6, a mathematics score of 19.4, and a composite score of 20.5; students with scores in the 75th percentile had an English score of 25.9, a mathematics score of 25.3, and a composite score of 25.7 (National Center for Education Statistics, 2017). The ACT Technical Manual (2017) reports the reliability and standard error measurement: "the reliability estimates are fairly high, with values over 0.9 for English, mathematics, Composite, STEM, and ELA scores, and values over 0.8 for reading and science. [Standard error measurement] values are fairly consistent across forms" (p. 10.2).

Three studies reviewed here measure the predictive value of standardized tests with chemistry courses. Carmichael, Bauer, Sevenair, Hunter, and Gambrell (1986) used the ACT test, and Spencer (1996) and Rixse and Pickering (1985) used the SAT. Carmichael et al. (1986) explored whether traditional variables that predict academic performance can also be used to predict performance in general chemistry at an institution with a predominantly black population. Their results with regard to the ACT composite score and subject sub-scores "confirm(ed) the widely held belief that mathematics sections of aptitude/achievement tests are reasonably good predictors of grades in general chemistry" (Carmichael et al., 1986, p. 335).

Spencer (1996) explored whether SAT Mathematics scores could be used to predict final grades at an Oberlin College organic chemistry course and determined "subsets of students with high SAT-M scores tend to achieve relatively high average grades, whereas those with low scores tend to achieve relatively lower average grades" (p. 1153). Rixse and Pickering (1985), using data from Columbia University students during 1978, determined that there was "significant correlation between the SAT scores and organic chemistry" (p. 313).

Academic Program of Study as a Predictor of Academic Performance

Students who enroll in the organic chemistry sequence do so because they are in a STEM curriculum that requires the courses. In 2015-2016, 18% of all bachelor's degrees awarded were in STEM fields - 331,000 graduates out of approximately 1.8 million total (National Center for Education Statistics, 2018a). Students in STEM majors are prone to changing majors. Astin and Astin (1992) conducted a longitudinal study of 27,065 freshmen at 388 four-year institutions from Fall 1985 through 1990 and determined that the percentage of students majoring in science, mathematics, or engineering fields (SME) dropped from 28.7% to 17.4%, with biological sciences seeing the greatest drop. Chen (2013) found that 48% of freshmen majoring in STEM fields changed majors out of STEM, including 46% of biological/life sciences majors (p. 14).

Studies that examine a student's major as a predictor of their academic performance in a specific course, whether organic chemistry, science-related, or not, are limited. Most studies explore the reverse relationship – whether a student characteristic leads to persistence in a major (Allen & Robbins, 2008; Allen, Robbins, Casillas, & Oh, 2008).

Initial Chemistry Course as a Predictor of Success in Follow-On Chemistry Course

The nature of curriculum design is that as a student progresses through courses, the courses become more challenging. It seems natural then that if students do not do well in an initial course of a curricular sequence, they will also likely not do well in the follow-on course. A review of literature consistently confirms that general chemistry or OC1 is a good predictor of success for the follow-on course, OC1 or OC2, respectively. A selection of the studies is below.

Rixse and Pickering (1985) reviewed grades and SAT scores for 117 freshmen entering Columbia University during the fall of 1978 to identify predictors of future academic success. While they found a significant correlation between SAT math and verbal scores with organic chemistry grades, they determined that the "freshman chemistry grade is a significantly better predictor ($p < 0.001$) of organic chemistry than either math or verbal SAT" (Rixse & Pickering, 1985, pp. 313–314).

More recently, Pursell (2007) analyzed predictive measures for organic chemistry performance, with performance defined as organic chemistry grade. The author's analysis and conclusion found "by far the strongest correlation (0.87) is Organic I GPA to Organic II GPA" (Pursell, 2007, p. 1451).

Jones and Gellene (2005) reported on the benefit of a remedial chemistry course required of students at Texas Tech University based on the results of a chemistry placement examination. A study of 6,000 students over a six-year period revealed two interesting findings: The "results indicated that little or no special benefit is gained by the successful completion of the remedial course" (Jones & Gellene, 2005, p. 1241) and "about 44% of students who successfully completed a remedial chemistry course did not enroll in the subsequent chemistry course for which they had been preparing" (Jones & Gellene, 2005, p. 1244). No data are provided about the topics, instructional strategies, or engagement in the remedial course.

Summary

As humans mature, the way they learn and the reasons why they learn change. A key change is a desire for self-direction, and learning that allows self-direction yields better engagement and better learning outcomes. However, students must be taught how to self-direct their learning, a lifelong skill, by having opportunities to practice learning activities. An opportunity to introduce self-directed learning is in OC2, a challenging but required course for many STEM majors.

This chapter reviewed a substantial number of studies on improving academic performance and outcomes in chemistry courses, but most of the studies are focused on general chemistry. Studies that report on organic chemistry are generally focused on the transition from general to organic. A paucity of studies examine academic success in a course sequence, although nearly all STEM curricula are designed with course sequences. The studies mention a varying range of intervention techniques, but there is a dearth of innovative learning aids such as e-books, which reports show students prefer and value.

CHAPTER 3: METHODS

Introduction

Chapter 1 introduced the study by providing background information, statement of the problem, purpose of the study, research questions, limitations and assumptions, and definition of terms. Chapter 2 presented a review of related literature divided into six sections: andragogy and adult education; self-directed learning; knowledge retention; use of e-books in higher education; results on academic performance from instructional interventions such as in-person boot camps, curricular changes, online homework, active learning, and flipped classrooms; and the impact of a range of learner characteristics on academic performance including: gender, race, admission type, cumulative GPA, standardized test scores, academic program of study or major, and grade in the first course of a course sequence.

Chapter 3 presents a description of the research methods used in this study. The research methods specifically include the design of the study, information on the population and sample, method of data collection, and the plan for data analysis. Details are also provided about the process for developing the primer e-book that was utilized as the self-directed intervention.

Purpose of the Study

The purpose of this study was to determine the impact of a self-directed learning intervention in the form of a primer e-book on academic performance in a follow-on organic chemistry course. Measuring this impact over several years and across multiple student characteristics can potentially provide an instructional strategy to improve student academic performance. The student characteristics used for this study included gender, race, admission type, cumulative GPA, standardized test scores, academic program of study, and grade in the first organic chemistry course.

Research Questions

The following research questions were used in this study:

1. What student characteristics including gender, race, admission type, cumulative GPA, standardized test scores, academic major, and grade in Organic Chemistry I, have a significant impact on the grade on a comprehensive final in an Organic Chemistry II course?

2. Controlling for the student characteristics that have a significant impact on the grade on a comprehensive final in an Organic Chemistry II course, is there a significant difference on the grade on a comprehensive final as the result of using a self-directed primer e-book?

3. Is there a significant difference in final exam performance for students based on gender or grade in Organic Chemistry I?

Design of Study

This study utilized a quasi-experimental quantitative approach. In many natural settings, including education research, Campbell and Stanley (1963) suggested that a researcher can "introduce something like experimental design into his scheduling of data collection procedures (e.g., the when and to whom of measurement), even though he lacks the full control over the scheduling of experimental stimuli (the when and to whom of exposure and the ability to randomize exposures) which makes a true experiment possible. Collectively, such situations can be regarded as quasi-experimental designs" (p. 34). Since this study did not allow control over assigning participants into groups, the group assignment could not be randomized.

E-Book Development

An electronic book, or e-book, is defined as an "electronic file that contains the complete text of a book that was initially published, or could have been published, in the usual printed form" (Reilly, 2003, p. 85). Features of an e-book include the ability to utilize electronic readers such as Apple iPad, Amazon Kindle, and similar products to not only passively read the text, but to actively highlight portions, zoom into graphics, view embedded video, look up definitions of words, and have text read out loud. In addition to the active engagement elements of e-book platforms, the user interfaces also incorporate traditional book features such as creating bookmarks and simulating flipping pages.

Topics covered in the e-book used for this study included those determined by a professor of chemistry to be most troublesome for students taking OC2. The topics included:

1. Drawing organic structures;
2. Functional groups;
3. Molecular formulae;
4. Structural options (constitutional isomers, conformations, monosubstituted cyclohexane, stereoisomers, alkenes, enantiomers, diastereomers, meso); and
5. Organic reactions (reaction mechanisms, bromination, oxidation, hydrogenation, resonance, rearrangements, substitution and elimination).

Content on the topics was developed by the same professor of chemistry. The types of content utilized in the e-book included text, video, graphics, suggested problems, and additional resources for further study. A total of 11 videos included animations of chemical reactions, narrated PowerPoint slideshows with graphical representations of topics, and an introduction featuring the professor. Topics for the video included hybridization, ethane animation, butane animation, cyclohexane conformations, conformational flip, cyclohexane animation, polarimeter, stereoisomers, and a bisection of 2,3-dihydroxysuccinic acid.

The animations were developed by a professional graphic designer hired to accurately depict the chemistry based on the specifications provided by the professor of chemistry. The animations were created using Maxon Cinema 4D Studio on an Apple iMac.

Approximately 34 graphics were embedded in the e-book and were largely comprised of organic structures drawn using the partially condensed or condensed structures using the latest available version of PerkinElmer ChemDraw Prime on an Apple iMac.

The e-book was developed using the EPUB 3.0 standard as published by the W3C in October 2011. The EPUB standard was used to provide the broadest device-agnostic capabilities. An alternative e-book format was iBook, which only operated on the Apple iOS platform at the time of the initial e-book development, and PDF (originally an abbreviation for Portable Document Format) which does not provide multimedia embedding capabilities. Apple Pages was utilized to develop the document, formatting, styling, and editing. An e-book cover was designed using Adobe Photoshop. Apple Pages was used to export the document as an e-book in EPUB format. The services of an information technology specialist were utilized to develop the EPUB file and upload it to the class website.

A guide document was also developed with relevant information and steps to access and utilize an e-book in EPUB format. The guide document included these topics:

1. What is an ePub?;
2. How do I view an ePub e-book on a Macintosh computer?;
3. How do I view an ePub e-book on a Windows computer?;
4. How do I view an ePub e-book on an iPhone or iPad?;
5. How do I view an ePub e-book in the Library or on a computer that is not mine?;
6. How do I view an ePub e-book on an Android smartphone or tablet?;

7. Accessibility options;
8. Viewing figures in more detail; and
9. Loading and viewing videos.

E-Book Distribution

The e-book, all videos, and the guide document were published to the course webpage for some organic chemistry sections between Fall 2014 and Fall 2018. In the course sections utilizing the e-book, the instructor introduced the e-book on the second day of class. Students were encouraged to bring their devices and/or laptops, and the instructor demonstrated downloading the e-book, opening it, and using some of the active features such as highlighting, built-in dictionary, and notes, as well as interacting with the multimedia features such as videos and graphics. The services of an information technology specialist were utilized to provide support to any student with technical difficulties downloading and accessing the e-book. The only technical issue that arose occurred when students on a PC with the Microsoft Windows 10 operating system utilized the Microsoft Edge web browser to download the EPUB file. In some rare cases, certain security settings for Microsoft Edge prevented downloading EPUB files. The remedy in this situation was to have the students use a different web browser such as Google Chrome or Mozilla Firefox.

Students on Apple devices such as Mac laptops or iPad utilized the free iBooks application to access and utilize the e-book. Students on the Windows platform utilized the free Adobe Digital Editions application to access the e-book. Students who did not have access to either application utilized Google Play Books, a free, web-based e-book library and reader platform, to access the e-book. The e-book was made available free to anyone with a link to the course web page, and students retained access to the e-book indefinitely. On the 10th day after start of the term (6th class day), students utilizing the e-book were given a 25-point quiz on the topics introduced by the e-book, with all points counting as extra credit toward the total points in the course. The practice of offering an extra credit activity to encourage self-directed learning is supported in literature (Parker & Loudon, 2013, p. 42).

Sample

The study sought to determine the effects of an intervention in the form of a self-directed e-book for a follow-on organic chemistry course. Between Fall 2014 and Fall 2018, there were 13 academic terms during which one, two, or three sections of OC2 were taught at a large public university in the southeastern United States. The thirteen terms had a total of 20 sections of OC2 taught by nine unique instructors, all possessing terminal degrees in chemistry.

The 20 sections featured enrollments ranging from 52 students to 214 students per section, with an average of 151 students each and a median of 160.5 students. A total of seven sections over the four years used the e-book. A total of 3,021 students were enrolled in these sections, but the sample size had to be adjusted to include only students for whom all characteristic data were available.

Data Collection

An exemption review application was submitted to the institution's Office of Research Compliance, which is responsible for managing the institutional review board for human subjects' research. The exempt review application included the project title, name and contact information of the principal investigator, name and contact information for the faculty advisor, and name and contact information for the department head. The form requested affirmation that the research was conducted in established or commonly accepted educational settings, involving normal educational practices. The application sought assurance that the research is not likely to adversely impact students' opportunity to learn or assessment of educators providing instruction. The form also required confirmation that this project was secondary research for which consent is not required, and that the information is recorded such that the subjects cannot be readily identified and that the researcher will not contact or seek to identify the subjects. The study did not target any special populations, including minors, pregnant women, prisoners, or those with physical and/or mental impairments. A waiver of consent was requested in the application. The application included attachments with certificates of completion for research ethics and compliance training using the Collaborative Institutional Training Initiative (CITI) Program.

The institution's central office responsible for collecting, maintaining, and reporting institutional data were the primary source of information used in the study's data analysis. The office provided the following data for students who registered for OC2 between Fall 2014 and Fall 2018: gender, race, admission type, cumulative GPA, SAT scores, ACT scores, term for completing OC2, identifier for instructor of OC2, academic major during the term during which OC2 was taken, recorded letter grade for OC2, and recorded letter grade for OC1.

The institution's office of audit, compliance, and privacy was contacted for permission to utilize historic academic performance data. Once permission was obtained, the institution's learning management system was used to retrieve data on final exam grades for students enrolled in the twenty sections of OC2 between Fall 2014 and Fall 2018.

Data Coding

The data received from the central office of institutional records included student characteristics on 3,021 students who registered for OC2 between Fall 2014 and Fall 2018. The following is a detail of the data that were received and how they were coded:

Gender. All student data included a gender of either male or female. Female was coded as 0, and Male was coded as 1.

Race. The data matches the definition and categories for race used by the NCES for IPEDS data.

- Category 1: White - A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.
- Category 2: Black or African American - A person having origins in any of the black racial groups of Africa.
- Category 3: Asian - A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian Subcontinent, including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam.
- Category 4: Hispanic or Latino - A person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin, regardless of race.
- Category 0: Due to the low representation, this study combined the following: American Indian or Alaska Native - A person having origins in any of the original peoples of North and South America (including Central America) who maintains cultural identification through tribal affiliation or community attachment; Native Hawaiian or Other Pacific Islander - A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands; Nonresident alien - A person who is not a citizen or national of the United States and who is in this country on a visa or temporary basis and does not have the right to remain indefinitely.

Academic majors. The students' program of study was coded using 2-digit CIP codes. The Classification of Instructional Programs, or CIP, is a taxonomic scheme of academic programs established in 1980 by the NCES. It has been revised four times, most recently in 2010.

CIP codes feature six digits across three levels of numbers to identify academic programs: the first two digits are a broad category (61 in total), followed by two digits that provide more specificity, and two additional digits for even more specificity. For example: a CIP code of 14 signifies engineering; a CIP code of 14.08 signifies civil engineering; and, a CIP code of 14.0804 signifies transportation and highway engineering.

In addition to IPEDS data, CIP codes are used by federal and state agencies for tracking academic program enrollment, labor supply-demand forecasting, tracking the development and consistency of offerings for education and training curriculum among other uses (National Center for Education Statistics, 2019b).

For the purposes of this study, the first two digits were used to determine the broad major area for the students enrolled in OC2. Based on data received, the students were assigned into five groups of majors:

- Group 1: Agriculture (CIP 01);
- Group 2: Natural resources and conservation (CIP 02), computer and info sciences (CIP 11), mathematics and statistics (CIP 27), physical science (CIP 40), science/math undeclared;
- Group 3: Engineering (CIP 14);
- Group 4: Biological sciences (CIP 26);
- Group 5: Health professions (CIP 51).

Some majors had low numbers of representation since OC2 is not a required course for all majors. For example, the data contained one history student (CIP 54), one human sciences student (CIP 19), nine education students (CIP 13). These cases did not have a representative sample and were not used in the study.

Admission type. If students started the institution as freshmen, they were coded 0. If the students transferred to the institution from either a two-year community college or a four-year institution, they were coded as 1. Some students were in the retrieved data categorized as other and no clear description was available on the variations represented by those categorized as other. This group was not used in the final analysis.

Standardized test scores. The institution used for this study prefers students to provide ACT scores. A significant number of students had ACT composite scores; therefore, that was the data used to represent standardized test scores. Several students had both SAT and ACT scores, and in those cases only the ACT composite score was used. Some students had only the SAT scores, and in those cases the SAT Total to ACT Composite table was used based on the 2018 Concordance Tables published by the College Board and ACT to convert the SAT Total score to the corresponding ACT Composite score (ACT, Inc. & The College Board, 2018, p. 2).

Organic Chemistry Course Grades. Final letter grades for both OC1 and OC2 were retrieved. The letter grades were re-coded thusly: A's were coded as 4, B's were coded as 3, C's were coded as 2, and D's were coded as 1. In OC2, students withdrawing from the course received a W for the grade, and it was coded as -1, and grades of F or failing were coded as 0.

Cumulative GPA. The cumulative GPA was used since it includes all attempted hours and does not remove grades due to grade forgiveness policies or other adjustments. The cumulative GPA is on a four-point scale.

Final Exam Score. All twenty sections of OC2 utilize a comprehensive final exam. This final exam grade was recorded out of 200 points. Several course sections did not report the final exam grade in the learning management system. These records were removed from analysis. Several students earned a grade of zero on the final exam, likely as a result of not attempting to take it. These grades were not removed from the final data analysis.

Data Analysis

The data were analyzed using IBM SPSS Statistics version 25 on a Macintosh computer. The split-file feature of SPSS was used to calculate in-group frequencies for students who used an e-book and students who did not use an e-book. Frequencies were calculated for gender, race, admission type, and major. Means and standard deviations were calculated for cumulative GPA, ACT Composite scores, OC1 grades, and the final exam raw score. The total number of students who took OC2 between Fall 2014 and Fall 2018 with a full data set reflected in this study was 2,099 students. Of these students, 1,279 students were in course sections that utilized the e-book, and 820 students were in course sections that did not utilize the e-book.

An independent samples t-test was used to ascertain if the two groups, students who used an e-book and students who did not, have a similar distribution with respect to their ACT Composite score and cumulative GPA; chi-square tests were used for gender, transfer status, and grade in OC1.

RQ 1

Research question 1 used backward elimination regression to determine which characteristics had a significant impact on students' performance on the cumulative OC2 final exam. The independent variables included gender, race, admission type, cumulative GPA, standardized test scores, academic major, and grade in OC1. Missing values were handled by excluding cases listwise.

RQ 2

Research question 2 used hierarchical multiple regression and retained the characteristics from RQ1 that had a significant impact on the final exam grade for step 1. In step 2, those characteristics were controlled, and the e-book was added. The dependent variable for both RQ1 and RQ2 was the final exam score, a continuous/scale variable measured out of a possible 200 points.

The assumptions for hierarchical multiple regression were tested in the following ways: The Durbin-Watson statistic was used to check for serial correlation, scatter plots were used to test for linearity and homoscedasticity, tolerance and the variance inflation factor (VIF) were used to test for multicollinearity, Mahalonobis distance compared with the chi-square distribution was used to identify outliers, and a histogram with a superimposed normal curve and a P-P plot were used to check for normality.

RQ3

Research question 3 aimed to determine how the use of a self-directed primer e-book impacted the final exam score based on gender or grade in OC1. The statistical test used to perform the data analysis was an analysis of covariance (ANCOVA). The ANCOVA for analyzing gender was run using gender and e-book usage as two factors, and OC1 grade and cumulative GPA as covariates. The ANCOVA for analyzing OC1 grade was run using OC1 grade and e-book usage as factors, with gender and cumulative GPA as covariates.

An alpha value of 0.05 was used throughout the study ($\alpha = 0.05$).

Summary

This chapter restated the purpose of the study and the research questions, and discussed the design of the study. The process for developing and distributing the e-book was detailed, including the topics that were incorporated into the self-directed e-book. The process for obtaining IRB approval was described. The plan for data collection and data coding was provided, and the data analysis steps were described for each of the three research questions.

CHAPTER 4: FINDINGS

Introduction

Chapter 1 introduced the study by providing background information, statement of the problem, purpose of the study, research questions, limitations and assumptions, and definition of terms. Chapter 2 presented a review of related literature divided into six sections: andragogy and adult education; self-directed learning; knowledge retention; use of e-books in higher education; results on academic performance from instructional interventions such as in-person boot camps, curricular changes, online homework, active learning, and flipped classrooms; and the impact of a range of learner characteristics on academic performance including: gender, race, admission type, cumulative GPA, standardized test scores, academic program of study or major, and grade in the first course of a course sequence. Chapter 3 presented a description of the research methods used in this study, specifically including the design of the study, information on the population and sample, method of data collection, and the plan for data analysis. The process for developing and distributing the e-book was also described.

In Chapter 4, the data and the corresponding findings are presented. The data analyses are presented for each of the three research questions.

Purpose of the Study

The purpose of this study was to determine the impact of a self-directed learning intervention in the form of a primer e-book on academic performance in a follow-on organic chemistry course. Measuring this impact over several years and across multiple student characteristics can potentially provide an instructional strategy to improve student academic performance. The student characteristics used for this study included gender, race, admission type, cumulative GPA, standardized test scores, academic program of study, and grade in the first organic chemistry course.

Research Questions

The following research questions were used in this study:

1. What student characteristics including gender, race, admission type, cumulative GPA, standardized test scores, academic major, and grade in Organic Chemistry I, have a significant impact on the grade on a comprehensive final in an Organic Chemistry II course?

2. Controlling for the student characteristics that have a significant impact on the grade on a comprehensive final in an Organic Chemistry II course, is there a significant difference on the grade on a comprehensive final as the result of using a self-directed primer e-book?

3. Is there a significant difference in final exam performance for students based on gender or grade in Organic Chemistry I?

Demographic Results

Between Fall 2014 and Fall 2018, there were 13 academic terms during which one, two, or three sections of OC2 were taught at a public university in the southeastern United States. The thirteen terms had a total of 20 sections of OC2 taught by nine unique instructors, all possessing terminal degrees in chemistry.

The 20 sections featured enrollments ranging from 52 students to 214 students per section, with an average of 151 students each and a median of 160.5 students. A total of seven sections over the four years used the e-book.

The data obtained from the central records office contained for all students who enrolled in OC2 between Fall 2014 and Fall 2018: gender, race, admission type, cumulative GPA, standardized test scores, academic major, grade in OC1, and grade in OC2, based on official institution records. Data obtained from the learning management system for the same course sections contained the final exam score.

After eliminating cases with incomplete data, 2,099 students remained in the sample. Of these 2,099 students, 1,279 students were in course sections that utilized an e-book, and 820 students were in course sections that did not utilize the e-book. Table 2 shows the demographic distribution amongst the sample and population.

Table 2

Gender and Race of Sample and Population

<table>
<tr><th>Category</th><th>All OC2, N=2,099</th><th>E-Book Yes, N=1,279</th><th>E-Book No, N=820</th><th>Institution-wide undergraduate[1]</th><th>All US Public, 4-yr undergrad[2,3]</th></tr>
<tr><td>Male</td><td>40.4</td><td>40.0</td><td>41.2</td><td>51.6</td><td>45.1</td></tr>
<tr><td>Female</td><td>59.6</td><td>60.0</td><td>58.8</td><td>48.4</td><td>54.9</td></tr>
<tr><td>White</td><td>79.2</td><td>77.9</td><td>81.3</td><td>79.2</td><td>54.6</td></tr>
<tr><td>Non-White</td><td>20.8</td><td>22.1</td><td>18.7</td><td>20.8</td><td>45.4</td></tr>
<tr><td>Black</td><td>8.8</td><td>9.2</td><td>8.0</td><td>5.4</td><td>11.1</td></tr>
<tr><td>Asian</td><td>5.0</td><td>5.3</td><td>4.5</td><td>2.3</td><td>7.2</td></tr>
<tr><td>Hispanic</td><td>3.8</td><td>4.1</td><td>3.2</td><td>3.4</td><td>18</td></tr>
<tr><td>Hawaiian / Pacific Islander</td><td rowspan="5">3.2</td><td rowspan="5">3.4</td><td rowspan="5">2.9</td><td><1</td><td><1</td></tr>
<tr><td>Native American/Alaskan</td><td><1</td><td><1</td></tr>
<tr><td>Two or More</td><td>2.2</td><td>3.7</td></tr>
<tr><td>Non-Resident</td><td>6.7</td><td>6.1</td></tr>
<tr><td>Unknown</td><td><1</td><td>-</td></tr>
</table>

Sources:
[1] Office of Institutional Research (2019)
[2] Gender: National Center for Education Statistics (2018b) Table 303.60
[3] Race: National Center for Education Statistics (2018a) Table 306.50

Test for Association and Common Distribution Among Groups

Gender. Of all OC2 students in the sample, 59.6% were female, and 40.4% were male. For the group of students using the e-book, 60% were female, and 40% were male; the group of students not using the e-book was 58.8% female and 41.2% male. A chi-square test for association was conducted between gender and e-book usage to ensure both groups had similar distribution of gender. The association was not statistically significant, $\chi^2(1) = 0.333$, $p = 0.564$.

Race. The race demographics for all OC2 students in the sample, as described in Table 2, were as follows: White, 79.2%; Black, 8.8%; Asian, 5.0%; Hispanic, 3.8%; and other or unknown, 3.2%. For students in the group using e-books, the racial breakdown was as follows: White, 77.9%; Black, 9.2%; Asian, 5.3%; Hispanic, 4.1%; and other or unknown, 3.4%. For the students in the group that did not use e-books, the racial breakdown was as follows: White, 81.3%; Black, 8.0%; Asian, 4.5%; Hispanic, 3.2%; and other or unknown, 2.9%. A chi-square test for association was conducted between race and e-book usage to ensure both groups had a similar distribution of race. All expected cell frequencies were greater than five, and the association was not statistically significant, $\chi^2(4) = 3.858$, $p = 0.426$.

Table 3

Sample and Group Means for Cumulative GPA and ACT Composite Score

Category	All OC2, *N*=2,099	E-Book: Yes	E-Book: No
Cumulative GPA	*M*= 3.29, *SD*= .51	*N*= 1,279, *M*= 3.273, *SD*=.50	*N*= 818, *M*= 3.304, *SD*=.52
ACT Composite score	*M*= 28.1, *SD*= 3.78	*N*= 1,204, *M*=28.07, *SD*=3.83	*N*= 783, *M*=28.14, *SD*=3.71

Cumulative GPA. Results of the independent samples *t*-test show the cumulative GPA of the group using the e-book (M = 3.273, SD = 0.50) was not statistically different than the cumulative GPA of the group that did not use the e-book (M = 3.304, SD = 0.52), $t(2095)$ = 1.386, p = 0.166.

ACT Composite Score. An independent samples *t*-test also showed that the ACT Composite score of the group using the e-book (M = 28.07, SD = 3.83) was not statistically different than the ACT Composite score of the group that did not use the e-book (M = 28.14, SD = 3.71), $t(1985)$ = 0.466, p = 0.656.

Admission Type. The total sample of OC2 students (n=2,099) had 1,782 students, or 84.9%, who started at the institution as freshmen, and 317 students, or 15.1%, who transferred to the institution from either a two-year community college or another four-year institution. With regard to group membership by e-book, 1,073 freshman-admit students used the e-book, 709 freshman-admit students did not use the e-book, 206 transfer students used the e-book, and 111

Table 4

Distribution of Students by Admission Type, N=2,099

Group	Status	Frequency	Percent
E-Book: No	Freshman	709	86.5
	Transfer	111	13.5
	Total	820	100
E-Book: Yes	Freshman	1073	83.9
	Transfer	206	16.1
	Total	1279	100

transfer students did not use the e-book. A chi-square test for association was conducted between admission type and e-book usage to ensure both groups had a similar distribution. The association was not statistically significant, $\chi^2(1) = 2.573$, $p = 0.109$.

OC1 Grade. The grade distribution of the OC2 students with respect to their grades in OC1 showed 25.5% of the students earned an A, 27.3% of the students earned a B, 32.3% earned a C, and 14.9% earned a D. A chi-square test for association was conducted between OC1 grade and e-book usage to ensure both groups had a similar distribution. The association was not statistically significant, $\chi^2(3) = 1.342$, $p = 0.719$.

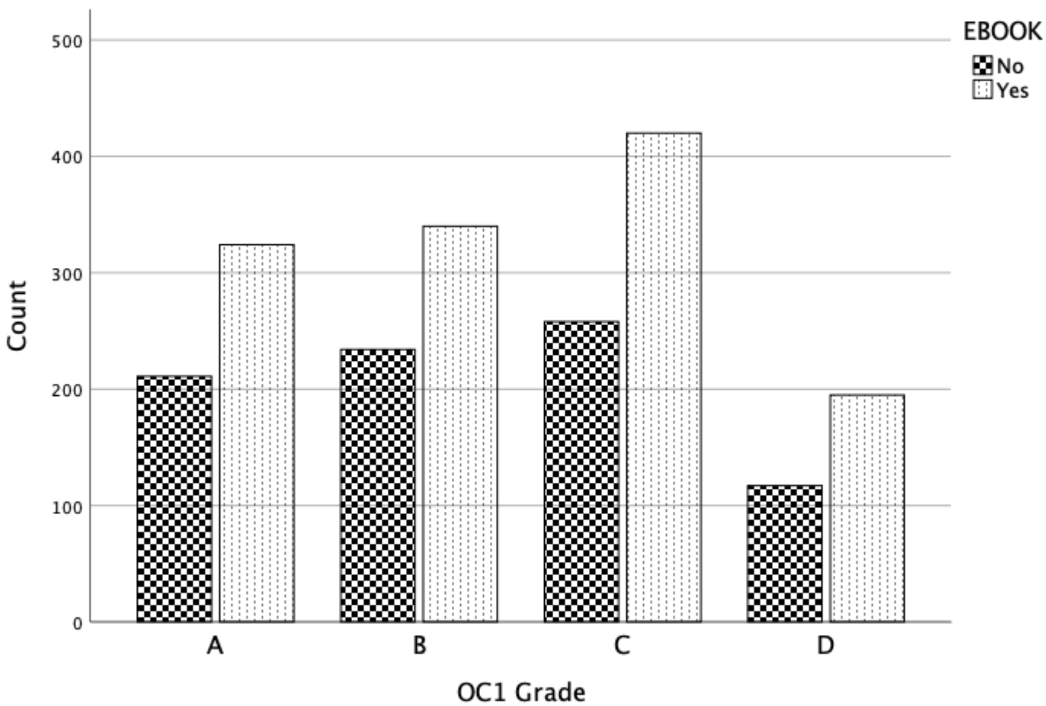


Figure 4. Distribution of Students by Grade in OC1, N=2,099

Table 5

Distribution of Students by Grade in OC1, N=2,099

Group	Grade	Frequency	Percent
E-Book: No	A	211	25.7
	B	234	28.5
	C	258	31.5
	D	117	14.3
	Total	820	100
E-Book: Yes	A	324	25.3
	B	340	26.6
	C	420	32.8
	D	195	15.2
	Total	1279	100

Research Question 1

What student characteristics including gender, race, admission type, cumulative GPA, standardized test scores, academic major, and grade in Organic Chemistry I, have a significant impact on the grade on a comprehensive final in an Organic Chemistry II course?

RQ1 aimed to determine, from a basket of student characteristics, which characteristics had a significant impact on students' performance on the cumulative OC2 final exam. Backward elimination regression was used to identify the characteristics that had a significant impact on the comprehensive final exam score. The dependent variable was the final exam score, a continuous/scale variable measured out of a possible 200 points. The independent variables included gender, race, admission type, cumulative GPA, standardized test scores, academic major, and grade in OC1. Table 6 details the regression model.

Table 6

Backward Elimination Regression Full Model and Restricted Model

	Dependent Variable: Comprehensive Final Exam					
	Full Model, n = 1,919			Restricted Model, n = 2,024		
Variable	ß	Zero-order	Partial	ß	Zero-order	Partial
Constant						
Gender	0.07^{a}	0.095	0.08	0.07^{f}	0.09	0.08
Race	0.02^{b}	-0.06	0.02			
Admission Type	-0.04^{c}	-0.08	-0.04			
GPA	0.39^{a}	0.53	0.32	0.38^{a}	0.52	0.32
Standardized Test Score	-0.01^{d}	0.25	-0.01			
Acad. Major	-0.01^{e}	0.08	-0.01			
OC1 Grade	0.22^{a}	0.48	0.20	0.23^{a}	0.48	0.20
R^2	0.317			0.309		
F	126.61^{a}			300.70^{a}		

Notes: $^{a}p < 0.001$; $^{b}p=0.39$; $^{c}p = 0.05$; $^{d}p = 0.65$; $^{e}p = 0.59$; $^{f}p = 0.001$;

The restricted model of OC1 grade, gender, and cumulative GPA to predict the comprehensive final exam score was statistically significant, $R^2 = 0.309$, $F(3, 2020) = 300.70$, $p < 0.001$. Table 6 details the regression model.

Assumptions

The following assumptions for backward elimination regression were checked: exclusion of outliers, serial correlation, linearity, homoscedasticity, multicollinearity, and normality. The Mahalanobis distance was calculated and compared with the cumulative distribution function for chi-square to identify outliers. Outliers were excluded from the final analysis. The Durbin-Watson statistic was 2.012, meeting the assumption of independence of observations. The histogram of standardized residuals indicated that the data contained approximately normally distributed errors, as did the normal *P-P* plot of standardized residuals, which showed points that were not completely on the line, but close.

Residuals were plotted to test for homoscedasticity, and visual inspection confirmed there was no violation of the assumption and the data met the assumptions for homogeneity of variance and linearity. Tests to determine that the assumption of collinearity was met indicated that multicollinearity was not a concern, with the lowest Tolerance = .574, and the highest VIF = 1.74.

Research Question 2

Controlling for the student characteristics that have a significant impact on the grade on a comprehensive final in an Organic Chemistry II course, is there a significant difference on the grade on a comprehensive final as the result of using a self-directed primer e-book?

Hierarchical multiple regression was used to determine if the addition of an e-book intervention improved the prediction of the comprehensive final exam score over and above OC1 grade, gender, and cumulative GPA alone. Table 7 contains details on the regression model. The full model of OC1 grade, gender, and cumulative GPA to predict the comprehensive final exam score was statistically significant, $R^2 = 0.309$, $F(3, 2020) = 300.70$, $p < 0.001$. The addition of the e-book to the prediction of the comprehensive final exam score led to a statistically significant increase in R^2 of 0.046, for a total $R^2= 0.355$, $F(4, 2019) = 278.00$, $p < 0.001$.

Table 7

Hierarchical Multiple Regression Predicting Comprehensive Final Exam Score from Gender, OC1 Grade, Cumulative GPA, and E-Book Usage, N=2,024

	Dependent Variable: Comprehensive Final Exam									
	Step 1					Step 2				
Variable	B	ß	Zero-order	Partial	Part	B	ß	Zero-order	Partial	Part
Constant	-11.29					-24.67*				
Gender	6.06	0.07	.09	.08	.06	6.34	.07**	.09	.08	.07
GPA	33.99	0.38	.52	.32	.29	34.53	.38*	.52	.34	.29
OC1 Grade	10.31	0.23	.48	.20	.17	10.11	.22*	.48	.21	.17
E-Book						20.19	.22*	.21	.26	.22
R^2	.309					.355				
F	300.70*					278.00*				
ΔR^2						.046				
ΔF						145.42*				

Notes: $n = 2{,}024$. $^{*}p<0.001$; $^{**}p=0.001$

Research Question 3

Is there a significant difference in final exam performance for students based on gender or grade in Organic Chemistry I?

While RQ1 identified the student characteristics that have a significant impact on a comprehensive final exam, and RQ2 identified the impact on the comprehensive final exam grade as a result of the use of a self-directed primer e-book, the aim of RQ3 was to determine how the use of a self-directed primer e-book impacted the final exam score based on gender or grade in OC1.

Gender

An ANCOVA was run using gender and e-book usage as two factors and cumulative GPA and OC1 grade as covariates. Adjusted means for final exam score by gender and e-book group are detailed in Table 8. The final exam score for females who used the e-book (M = 136.15, SE = 1.38) was greater than females who did not use an e-book (M = 115.98, SE = 1.69), or males who did not use an e-book (M = 122.29, SE = 2.02). Despite this difference, there was not a statistically significant difference found in final exam scores by gender between the group that used the e-book and the group that did not use the e-book, $F(1, 2018) < 0.001$, $p = 0.989$, partial $\eta^2 < 0.001$.

Table 8

Adjusted Means, Standard Error, and Confidence Intervals on Final Exam Score for Gender Grouped by E-Book Usage

Ebook	Gender	Adj. Mean	n	Std. Error	95% Conf. Interval Lower	Upper
Yes	Female	136.15	724	1.38	133.45	138.86
	Male	142.51	482	1.70	139.19	145.84
	Total	139.33	1206	1.09	137.20	141.47
No	Female	115.98	482	1.69	112.67	119.29
	Male	122.39	336	2.02	118.33	126.26
	Total	119.14	818	1.31	116.56	121.71

OC1 Grade

An ANCOVA was run using OC1 grade and e-book usage as two factors and cumulative GPA and gender as covariates. Adjusted means for final exam score by OC1 grade and e-book group are detailed in Table 9. There was not a statistically significant difference in final exam scores by OC1 grade between the group that used the e-book and the group that did not use the e-book, $F(3, 2014) = 1.512$, $p = 0.209$, partial $\eta^2 = 0.002$.

Table 9

Adjusted Means, Standard Error, and Confidence Intervals on Final Exam for OC1 Grades Grouped by E-Book Usage

Ebook	OC1 Grade	Adj. Mean	n	Std. Error	95% Conf. Interval Lower	95% Conf. Interval Upper
Yes	A	152.94	316	2.29	148.46	157.43
	B	142.09	328	2.04	138.08	146.10
	C	133.11	394	1.91	129.34	136.85
	D	118.66	168	3.08	112.62	124.70
	Total	136.70	1206	1.09	137.20	141.47
No	A	130.90	209	2.75	125.51	136.28
	B	122.46	234	2.43	117.69	127.22
	C	110.28	258	2.34	105.70	114.86
	D	106.67	117	3.64	99.53	113.80
	Total	117.58	818	1.31	116.56	121.71

Summary

Chapter 4 presented the findings and statistical analyses for the study. Data were obtained from an institutional records database of demographics and grades including gender, race, admission type, cumulative GPA, standardized test scores, academic major, and grade in OC1 for 2,099 students who took OC2 between Fall 2014 and Fall 2018. Data from a learning management system for the same students provided grades on a comprehensive final exam.

Independent samples t-test showed the demographics in the two groups, students who used an e-book and students who did not, had a similar distribution with respect to their ACT Composite ($t(1985) = 0.466$, $p = 0.656$) score and cumulative GPA ($t(2095) = 1.386$, $p = 0.166$). Chi-square tests used for remaining demographics also showed the two groups did not have a statistically significant association for gender ($\chi^2(1) = 0.333$, $p = 0.564$), race ($\chi^2(4) = 3.858$, $p = 0.426$), admission type ($\chi^2(1) = 2.573$, $p = 0.109$), and grade in OC1 ($\chi^2(3) = 1.342$, $p = 0.719$).

Research question 1 aimed to determine which characteristics had a significant impact on students' performance on the cumulative OC2 final exam. The model of OC1 grade, gender, and cumulative GPA to predict the comprehensive final exam score was statistically significant, $R^2 = 0.309$, $F(3, 2020) = 300.70$, $p < 0$. The analyses accounted for outliers and assumptions of serial correlation, linearity, homoscedasticity, multicollinearity, and normality.

Research question 2 asked if the use of a self-directed primer e-book had an impact on the final exam grade for OC2 students. Hierarchical multiple regression was used to determined that using the e-book did have a statistically significant positive impact on student grade on the final exam above and beyond the variables identified in RQ1, $R^2= 0.355$, $F(4, 2019) = 278.00$, $p < 0.001$.

Research question 3 aimed to determine if the use of a self-directed primer e-book significantly impacted the final exam score for students by gender or based on their grade in OC1. An analysis of covariance (ANCOVA) by gender and e-book usage accounting for OC1 grade and cumulative GPA as covariates determined there was no statistically significant difference on the final exam score by gender between students who used the e-book and those who did not, $F(1, 2018) < 0.001$, $p = 0.989$, partial $\eta^2 < 0.001$. An ANCOVA by OC1 grade and e-book usage, accounting for gender and cumulative GPA as covariates, determined there was no statistically significant difference on the final exam score based on the students' OC1 grade between students who used the e-book and those who did not, $F(3, 2014) = 1.512$, $p = 0.209$, partial $\eta^2 = 0.002$.

CHAPTER 5: SUMMARY, CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

Introduction

Chapter 1 introduced the study by providing background information, statement of the problem, purpose of the study, research questions, limitations and assumptions, and definition of terms. Chapter 2 presented a review of related literature divided into six sections: andragogy and adult education; self-directed learning; knowledge retention; use of e-books in higher education; results on academic performance from instructional interventions such as in-person boot camps, curricular changes, online homework, active learning, and flipped classrooms; and the impact of a range of learner characteristics on academic performance including: gender, race, admission type, cumulative GPA, standardized test scores, academic program of study or major, and grade in the first course of a course sequence. Chapter 3 presented a description of the research methods used in this study, specifically including the design of the study, information on the population and sample, method of data collection, and the plan for data analysis. The process for developing and distributing the e-book was also described. In Chapter 4, the results were presented for each of the research questions. Chapter 5 provides a summary of the findings, and a discussion of conclusions, implications, and recommendations.

Purpose of the Study

The purpose of this study was to determine the impact of a self-directed learning intervention in the form of a primer e-book on academic performance in a follow-on organic chemistry course. Measuring this impact over several years and across multiple student characteristics can potentially provide an instructional strategy to improve student academic performance. The student characteristics used for this study included gender, race, admission type, cumulative GPA, standardized test scores, academic program of study, and grade in the first organic chemistry course.

Research Questions

The following research questions were used in this study:

1. What student characteristics including gender, race, admission type, cumulative GPA, standardized test scores, academic major, and grade in Organic Chemistry I, have a significant impact on the grade on a comprehensive final in an Organic Chemistry II course?

2. Controlling for the student characteristics that have a significant impact on the grade on a comprehensive final in an Organic Chemistry II course, is there a significant difference on the grade on a comprehensive final as the result of using a self-directed primer e-book?

3. Is there a significant difference in final exam performance for students based on gender or grade in Organic Chemistry I?

Summary

Data for this study were obtained from an institutional records database and the learning management system of a large, four-year, public university. The demographics and grades data included gender, race, admission type, cumulative GPA, standardized test scores, academic major, grade in OC1, and score on the comprehensive final exam administered at the end of OC2 for 2,099 students who took OC2 between Fall 2014 and Fall 2018. The thirteen terms had a total of 20 sections of OC2 taught by nine unique instructors, all possessing terminal degrees in chemistry. The 20 sections featured enrollments ranging from 52 students to 214 students per section, with an average of 151 students each and a median of 160.5 students. A total of seven sections over the four years used the e-book. A total of 3,021 students were enrolled in these sections, but the sample size had to be adjusted to include only students for whom all characteristic data were available.

Independent samples t-test showed the demographics in the two groups, students who used an e-book and students who did not, had a similar distribution with respect to their ACT Composite ($t(1985) = 0.466$, $p = 0.656$) score and cumulative GPA ($t(2095) = 1.386$, $p = 0.166$). Chi-square tests used for remaining demographics also showed the two groups did not have a statistically significant association for gender ($\chi^2(1) = 0.333$, $p = 0.564$), race ($\chi^2(4) = 3.858$, $p = 0.426$), admission type ($\chi^2(1) = 2.573$, $p = 0.109$), and grade in OC1 ($\chi^2(3) = 1.342$, $p = 0.719$).

Research question 1 aimed to determine which characteristics had a significant impact on students' performance on the cumulative OC2 final exam. The restricted model of OC1 grade, gender, and cumulative GPA to predict the comprehensive final exam score was statistically significant, $R^2 = 0.309$, $F(3, 2020) = 300.70$, $p < 0$. The analyses accounted for outliers and assumptions of serial correlation, linearity, homoscedasticity, multicollinearity, and normality.

Research question 2 asked if the use of a self-directed primer e-book had an impact on the final exam grade for OC2 students. Hierarchical multiple regression was used to determine that using the e-book did have a statistically significant positive impact on student grade on the final exam above and beyond the variables identified in RQ1, $R^2= 0.355$, $F(4, 2019) = 278.00$, $p < 0.001$. Adding the e-book computed to a change in R^2 equal to 4.6%.

Research question 3 aimed to determine if the use of a self-directed primer e-book significantly impacted the final exam score for students by gender or based on their grade in OC1. An analysis of covariance (ANCOVA) by gender and e-book usage accounting for OC1 grade and cumulative GPA as covariates determined there was no statistically significant difference on the final exam score by gender between students who used the e-book and those who did not, $F(1, 2018) < 0.001$, $p = 0.989$, partial $\eta^2 < 0.001$. An ANCOVA by OC1 grade and e-book usage, accounting for gender and cumulative GPA as covariates, determined there was no statistically significant difference on the final exam score based on the students' OC1 grade between students who used the e-book and those who did not, $F(3, 2014) = 1.512$, $p = 0.209$, partial $\eta^2 = 0.002$.

Conclusions

Female Students

Females have consistently made up more than half of college enrolled students in the past five years (National Science Foundation, National Center for Science and Engineering Statistics, 2019), and that enrollment distribution was similar to the gender distribution in OC2 courses in the sample, where 59.6% were female. Studies consistently show that female students earn higher undergraduate GPAs than male students (Buchmann & DiPrete, 2006), and at least one study across 16 institutions found that female students earned a higher grade in college-level physics courses (Tai & Sadler, 2001). That same outcome was not borne out in OC2 final exam performance in this study.

Results of RQ1 and RQ2 showed gender was a significant predictor of final exam scores, and male students in this study consistently performed better than female students across both the control and the experiment groups. Nearly two of five females who switched out of STEM majors identified lost confidence due to low grades in early years as a factor for changing majors (Seymour, 1995, p. 444). OC2 comprehensive final exam grades indicated synchronicity.

RQ3 sought to test if the use of a self-directed primer e-book would impact female students disproportionately, since several studies have shown that female students perform better in courses utilizing teaching methods more engaging than lecture (Freeman et al., 2014; Preszler, 2009). The results of the ANCOVA in RQ3 did not indicate any interaction between gender and e-book usage impacting final exam scores, but female students who used the e-book earned 10.1%, or one letter-grade, higher on the final exam than their counterparts who did not use the e-book.

Race

Between 2006 and 2016, the share of non-white students enrolled as undergraduates in 4-year institutions in the United States has increased from 38% to 47.3% (National Science Foundation, National Center for Science and Engineering Statistics, 2019). The number of non-white students earning a bachelor's degree in a STEM field nearly doubled between 2008-09 and 2015-15 (National Center for Education Statistics, 2019a). Despite these national trends, the racial distribution for OC2 students in this study was largely white (79.2%). This mirrored the institution's enrollment, which was one-fifth non-white. Regardless, there may be opportunities at this institution to expand access to non-white students in STEM courses to align more closely with national trends. Despite many studies indicating that non-white students struggle in college (Buchmann & DiPrete, 2006; Kao & Thompson, 2003), race was not a significant predictor for performance on the OC2 comprehensive final exam.

Cumulative GPA

Several studies pointed to cumulative GPA being the strongest predictor of academic performance in an organic chemistry course (Szu et al., 2011; Wright et al., 2009). This study revealed the same result, with each point change in cumulative GPA accounting for approximately 34-points on the final exam. A student with a 4.0 cumulative GPA will receive a grade of 68% (almost a C letter grade) on the comprehensive final exam before any other factor is included.

Grade in Previous Course

Literature consistently confirms that general chemistry or OC1 is a good predictor of success for the follow-on course, OC1 or OC2, respectively (Pursell, 2007; Rixse & Pickering, 1985). RQ1 results showed that OC1 grade was a significant factor for performance on the OC2 comprehensive final exam. RQ3 attempted to determine if students utilizing the self-directed primer e-book had disproportionately better outcomes on their OC2 final exam based on their OC1 grade. The results showed there was no interaction between OC1 grades and utilizing the e-book. However, the means on the final exam were higher across the board for the experiment group. The analysis showed students who earned a "C" in OC1 failed the comprehensive final in OC2 (M = 110.28) with an average grade of 55.1%, and a maximum grade of 57.4%. However, students who earned a "C" in OC1 and were in the OC2 section with a self-directed primer e-book averaged a "C" grade on the final (M = 133.11), earning on average 66.56% and no lower than 64.7% on the final exam. Students who earned an A, B, or C in OC1 on average received about a letter grade higher on the final exam in OC2 than their control group counterpart.

Self-Directed Primer E-Book

The studies that reported academic performance numbers from intervention in chemistry courses ranged from no significant impact (Siebert et al., 2017), to 3% to 5% increase in the final grade (Fischer et al., 2019; Parker & Loudon, 2013). A study reported higher test scores, but did not include numerical results (Penn et al., 2000). The regression model resulting from RQ2 showed the primer e-book had an impact of about 20.19 points added to the comprehensive final exam, or about 10 percentage points. This means the self-directed primer e-book was equally or more effective as an intervention.

Implications

The self-directed primer e-book in this study did yield a significant positive result on the final exam score, but the overall grades on the OC2 final exam across all students were still low. Students who need to know organic chemistry for future careers risk either changing majors or performing poorly in the future when their organic chemistry knowledge needs to be recalled. A meta-analyses of 225 studies compared lecture-based teaching with more active and engaged student learning and revealed that students perform significantly better academically with active learning approaches (Freeman et al., 2014).

Additionally, while nearly 60% of students enrolled in OC2 were female, their performance lagged behind their male counterparts. This performance lag was not in keeping with typically better performance from female students in college courses. When females switched from science majors to non-science majors, they cited lack of help with academic problems as a reason (Seymour, 1995), yet many interventions were of more benefit to male students (Turner & Lindsay, 2003). Therefore, strategies should be explored that address the OC2 performance lag for females in a way that does not disadvantage male students.

This study can be repeated with greater control on the experiment. For example, a common final exam graded in a more consistent way could provide more reliable results.

Recommendations for Future Study

Online databases of scholarly publications allowed convenient searches for relevant research on practices that impact academic performance. Despite this convenience, there was a scarcity of published research on interventions to improve student academic performance in STEM generally, and organic chemistry specifically. Studies that contribute to the scholarship of teaching and learning (SoTL) are recommended. SoTL involves instructors undertaking a systematic inquiry on student learning. Cross and Steadman (1996) offer that SoTL is focused on student learning but faculty-directed, relevant to their teaching experiences, continual, and makes the results public. There are tremendous opportunities for SoTL research, and the iterative nature of how college courses are offered creates way to conduct the research incrementally. The following research topics are recommendations for future studies:

1. Research on self-directed interventions as a bridge in other STEM course sequences will create insight on strategies to improve student outcomes.
2. Research that changes the format of the intervention from an e-book to a self-directed online course will provide further insight on the efficacy of emerging teaching and learning modalities and platforms.
3. With due consideration for privacy, technological platforms can be used to determine how much time students spend engaging with certain self-directed activities so a better determination can be made of the impact of the interventions.
4. Correlation between specific concepts covered in the primer and the student performance on the assessment of the application of those concepts in the follow-on course can better inform instructional and practice strategies.
5. Using self-directed and self-paced learning could have a greater benefit for students with chronic illness or other accessibility needs.

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Location: 115 Ramsay Hall **Phone:** 334-844-5966 **Email:**IRBAdmin@auburn.edu

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1. PROJECT IDENTIFICATION **Date** August 10, 2019

a. Project Title Impact on Academic Performance of a Self-Directed Primer E-Book in a Follow-On Organic Chemistry Course

b. Principal Investigator Syed Asim Ali Degree(s) M.S.
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c. Project Personnel (other PI) – Identify all individuals who will be involved with the conduct of the research and include their role on the project. Role may include design, recruitment, consent process, data collection, data analysis, and reporting. Attach a table if needed for additional personnel.

Personnel Name__________ Degree (s) __________
Rank/Title__________ Department/School__________
Role__________
AU affiliated? ☐ YES ☐ NO If no, name of home institution __________
Plan for IRB approval for non-AU affiliated personnel? __________

Personnel Name__________ Degree (s) __________
Rank/Title__________ Department/School__________
Role__________
AU affiliated? ☐ YES ☐ NO If no, name of home institution __________
Plan for IRB approval for non-AU affiliated personnel? __________

Personnel Name__________ Degree (s) __________
Rank/Title__________ Department/School__________
Role__________
AU affiliated? ☐ YES ☐ NO If no, name of home institution __________
Plan for IRB approval for non-AU affiliated personnel? __________

d. Training – Have all Key Personnel completed CITI human subjects training (including elective modules related to this research) within the last 3 years? YES ☒ NO ☐

The Auburn University Institutional Review Board has approved this Document for use from
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