EXPLORING THE RELATIONSHIP BETWEEN TECHNOLOGY USE AND STUDENT PERFORMANCE IN DEVELOPMENTAL MATHEMATICS

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by

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DEDICATION

This dissertation is dedicated to my loves. Adeline and Elliott, you two are the bookends of my doctoral journey. And, of all the roles I have had in life, being your mommy is, hands-down, the best one I have the privilege of holding. I love you both with every bit of me.

ABSTRACT

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Rooted in learning theory and developmental psychology, the field of developmental education is concerned with addressing underprepared students' needs for growth. Much of this development relates to college readiness, thus students considered underprepared for college-level coursework are referred to developmental education coursework in subjects like reading, writing, and mathematics. This approach is similarly taken in Texas, the setting for this study, with the Texas Success Initiative Assessment as the approved instrument for assessing students' college readiness. In Texas, legislation also has been used to govern developmental education programs, such as through state administrative and education codes levying various requirements on the higher education institutions at which developmental education is offered. Of particular interest, a state mandate exists wherein these institutions must provide technology-mediated developmental education. Texas policies also are focused on student performance, defined as students' achievement of state-established benchmarks on the state assessment. For these reasons as well as the wealth of literature about technology in developmental mathematics, this dissertation study explored the relationship between technology use and student performance in developmental mathematics courses.

The study setting was a four-year public university in Texas through which archival data relevant to technology use and student performance were explored to answer two research questions. One question focused on the relationship between technology use and student performance in developmental mathematics courses, and the second question focused on technology use in developmental mathematics courses in relation to student performance in gatekeeper, college-level mathematics courses. Through an application of the I-E-O model, data were analyzed using the chi-square test of association with relevant descriptive statistics and frequencies computed. Technologies considered for analyses were graphing calculators, scientific calculators, learning management systems, online homework, software, online supplements, and e-textbooks. The results of analyses indicated statistically significant associations between technology use overall and student performance in developmental mathematics courses as well as five of the seven technologies. Conversely, statistically significant associations between technology use overall in developmental mathematics courses and letter grades earned in gatekeeper mathematics courses did not exist; however, statistically significant associations were identified regarding two technologies: learning management systems and e-textbooks.

KEY WORDS: Developmental education; Developmental mathematics; College-level mathematics; Gatekeeper mathematics; Student performance; Texas Success Initiative Assessment; Educational technology; Instructional technology.

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I want to acknowledge the faculty of the Department of Educational Leadership, those I learned from through coursework and others who saw this dissertation along the way. Your input—especially with the earliest drafts—made me a (statistically) significantly better writer. I also must express gratitude to my wonderful colleagues, past and present, at the McGovern Center. You are a dedicated group of educators and scholars, and I appreciate your giving me space to find my niche and explore my role.

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CHAPTER I

Introduction

Rooted in both learning theory and developmental psychology, developmental education is a field focused on addressing students' needs for growth and development through research, policy, and practice (Casazza, 1999). The phrase *developmental education* is not new, but it may be better known as *remedial education* and as courses or programs for *college readiness* (Casazza, 1999; Schak et al., 2017). Developmental education practices incorporate comprehensive and holistic approaches, assisting students with support services such as academic advising and tutoring, and providing developmental education coursework (Casazza, 1999). Students referred to developmental education are those considered underprepared for college-level coursework, and they work with developmental educators, including instructors and advisors, who promote students' intellectual and affective growth (Casazza, 1999; Moss & Yeaton, 2006). Efforts of developmental educators are guided frequently by research and best practices, such as those described by Boylan (2002), and steered by state policies from agencies like the Texas Higher Education Coordinating Board (Texas Higher Education Coordinating Board [THECB], 2013).

Background of the Study

Research on developmental education varies, ranging from studies about the percentage of students who successfully complete developmental education coursework (Moss & Yeaton, 2006; MDC, 2013; Noble & Sawyer, 2013; Overby, 2004) to a systematic review of what happens to students after they place into developmental education (Valentine et al., 2017). Additional studies of developmental education focus not on student outcomes but on the attributes of the programs designed to educate underprepared students (Boylan & Saxon, 2006; Hanover Research, 2014; Neuburger et al., 2014). Study of both developmental education students and developmental education programs is necessary considering 68% of students attending two-year institutions and 39% of students attending four-year institutions in the United States are considered underprepared for college-level courses (Chen & Simone, 2016). In Texas alone, these estimates range from 40% to 60% of incoming community college and 27% to 64% of university students who place into developmental education programs—a noteworthy figure considering nearly 1.4 million students are enrolled in public two- and four-year higher education institutions in the state (Boylan & Saxon, 2006; THECB, 2016a; THECB, 2017d). Of these students, more than half of those enrolled attend public community colleges (THECB, 2017d).

Developmental education is considered a foundational element of community colleges in Texas, in large part because these institutions provide coursework and programs to higher proportions of underprepared students (Carr, 2012; Schak et al., 2017). Formally, “public junior colleges, public state colleges, and public technical institutes” are primarily responsible for providing developmental education to underprepared higher education students (3 Tex. Edu. Code § 61.07611, 2017). Nonetheless, most—if not all—public four-year institutions in Texas also deliver developmental education to higher education students not meeting college-level standards (THECB, 2018b). Developmental education is addressed in Texas policy through the *Comprehensive College Readiness and Success Models for 60x30TX*, the *2012-2017 Statewide Developmental Education Plan*, and the Texas Success Initiative (TSI) through the Texas Administrative Code and Texas Education Code (3 Tex. Edu. Code § 51.336, 2017; THECB, 2017a; THECB, 2017b).

Developmental education programs are intended to be comprehensively and holistically supportive of students, incorporating a wide range of program components to accomplish this purpose. For Texas institutions, this may involve mandatory academic advising, career counseling, veteran's affairs offices, and more, all of which are reported in annual program surveys submitted to the state (THECB, 2018b). A representative of each Texas institution completes the Developmental Education Program Survey, and the responses are retained by the Texas Higher Education Coordinating Board (THECB, 2010). Questions include whether developmental education programs are centralized or guided by mission statements and whether academic advising is made available and required of developmental education students (THECB, 2010). Indeed, many of these developmental education program components are reported in the literature. For instance, academic advising and mandatory orientation were addressed by Fowler and Boylan (2010) who explored the effects of these components on student success and retention, and Gallard et al. (2010) who studied the impact of tutoring on student success in developmental education courses through degree completion.

A particular program component worth considering is the use of technology to support underprepared students in developmental education. One reason a consideration of this program component is necessary is the rising number of underprepared students entering higher education institutions, leading states like Texas to establish policies aimed at providing effective and efficient solutions in developmental education (McGruder, 2016). Of note is Texas Senate Bill 162 of the 82nd Texas Legislature

(Signed by Governor Perry on June 17, 2011), which set forth changes to developmental education.

The bill included a requirement for technology use and assigned primary responsibility of providing developmental education for underprepared students to public two-year higher education institutions and other institutions, as designated within Texas Education Code (McGruder, 2016; 3 Tex. Educ. Code § 61.07611, 2011). Furthermore, many institutions have increasingly incorporated technology into developmental education and other curricula through early alert systems (Booth et al., 2014), learning management systems (Adams, 2014; David et al., 2008), learning assistance centers (Caverly, 1995; Perin, 2004), educational software (Cederholm, 2010) and classrooms designed as learning labs (Parisi & Graziano-King, 2011). Yet another reason to study this topic is, unlike other program components mentioned previously (i.e., academic advising, counseling, tutoring), the effectiveness of technology used to support developmental education students and programs is less prevalent in the literature (Saxon et al., 2016). Martirosyan et al. (2017) agreed, “Because the state of Texas requires the integration of technology into developmental education courses, it is important to examine the current state of technology integration in Texas higher education” (p. 16).

The incorporation of technology in education is, by no means, a new subject. Indeed, technology has been in the classroom for nearly a century, tracing back to Pressey’s (1926) machine designed to drill and test students, and continuing with the proliferation of personal desktop computers and educational software in the 1970s through 1990s (Holmes & Gardner, 2006). Technology use is both off- and online and includes computer-aided instruction, mobile technology, and distance education

(Polczynski, 2013). Despite a lack of studies about the effectiveness or benefits of using technology in developmental education, reports of technology integrated into instructional practices in developmental education were found in the literature. Brothen (1998) described technology as an add-on to traditional lectures. Caverly and MacDonald (2003) explained that portable devices such as PDAs and smartphones offered study apps.

Walker (2017) reported the results of assigning computer-aided homework in a blended and compressed developmental mathematics course. Some researchers found more technology decreased student success (Boylan, 2002; Boylan et al., 1992; Pierce, 2012). Another researcher reported mixed results with integrated technology (Walker, 2017). Finally, Cederholm (2010) suggested that technology could successfully support developmental education. Developmental education classes have featured educational software, such as MyMathLab and ALEKS, used the Emporium Model to bring students into the computer lab to learn mathematics, and incorporated assistive technology in reading and writing (Engstrom, 2005; Epper & Baker, 2009; Rutschow & Schneider, 2011; Williams, 2016).

Despite the wide range of publications, there did not appear to be consensus on what the best practices and specific roles of technology in developmental education should be. For instance, publications about technology in developmental education seemed limited to case studies of technology use in a single institution or classroom (David et al., 2008; Engstrom, 2005), comparative studies of student success in a technology-enhanced course versus a traditional course (Cederholm, 2010), and a synthesis of technologies used by developmental education instructors (Skidmore et al., 2012). Epper and Baker (2009) offered descriptions of current uses and emerging practices of technology in developmental mathematics. The technology practices discussed by the authors included computer-assisted instruction used to supplement instruction, including commercial products like MyMathLab, ALEKS, and more (Epper & Baker, 2009). Yet other examples included technology practices of specific institutions and states, such as modularization used in four Tennessee colleges, web-based workspaces across the California State University system, computer-assisted instruction at Los Medanos College and Ivy Tech Community College to support or accelerate courses, and even a fully online accelerated program at Colorado Community Colleges Online (Epper & Baker, 2009).

Additionally, Martirosyan et al. (2017) identified both challenges to and best practices of integrating technology in developmental education teaching, as reported by developmental education instructors. For example, among developmental education faculty who did not report technology use, common challenges included the lack of technology and support at their institutions, that technology was time-consuming and reduced instructional time, and, still, nearly a quarter of faculty cited a preference for traditional instruction over technology-aided approaches (Martirosyan et al., 2017). These two studies (Epper & Baker, 2009; Martirosyan et al., 2017) were, perhaps, the most notable discussions of technology because each study detailed how technology was used in selected developmental education programs; however, these studies served as summaries of technology use rather than prescriptive guidelines for incorporating technology in the broader developmental education setting.

Background of the Texas' Developmental Education Plan

Both Texas Administrative Code and Texas Education Code include guidelines and requirements for developmental education, particularly in the form of the Texas Success Initiative, or TSI (Saxon & Slate, 2013). Guidelines of the TSI require assessment of students' college readiness, academic advising, student support services, and incorporating research-based best practices into developmental education programs (THECB, 2014b). The THECB expanded upon existing developmental education efforts under the umbrellas of the *Comprehensive College Readiness and Success Models for 60x30TX* and *Statewide Developmental Education Plan*, both of which prescribe requirements for institutions at which developmental education is provided for underprepared students (THECB, 2017a; THECB, 2017b). In the case of the *2012-2017 Statewide Developmental Education Plan*, the overall vision was to improve students' success in developmental education (THECB, 2012). This idea was guided by a vision statement and nine goals which outline developmental education efforts to take place through fall 2017 (THECB, 2012).

The first goal was to assign public two-year colleges the primary responsibility for providing developmental education to underprepared students (THECB, 2012). In the Texas Education Code, the responsible colleges are listed as "public junior colleges, public state colleges, and public technical institutions," which are defined in Chapter 61 (3 Tex. Educ. Code § 61.07611, 2017). The state comptroller maintains the list of public junior colleges, which includes 43 community and junior colleges, and the Texas Education Code defines public state colleges and technical institutions as Lamar State College-Orange, Lamar State College-Port Arthur, Lamar Institute of Technology, and the Texas State Technical College (3 Tex. Educ. Code § 61.003, 2013). Notably, the designation of responsibility to public two-year institutions did not change requirements for other higher education institutions, including four-year universities, at which developmental education is available (3 Tex. Educ. Code § 61.07611, 2017).

Indeed, all higher education institutions at which developmental education courses and programs are available must adhere to requirements of and amendments to the Texas Education Code whether or not the institution is designated with primary responsibility for developmental education (3 Tex. Educ. Code § 61.07611, 2017). The second goal of the plan is required use of technology in developmental education programs. Technology use is to be consistent with best practices and should effectively and efficiently "provide developmental education to students" (THECB, 2012, p. 9). To improve underprepared students' success as well as their access to and acceleration in developmental education, the third goal states "promising practices and/or programs" should be scaled (THECB, 2012, p. 10).

The fourth and fifth goals of the *Statewide Developmental Education Plan* were to improve advising and counseling services and increase professional development for developmental education faculty and staff, respectively (THECB, 2012). The sixth goal required improvement of developmental education programs' quality and effectiveness via continuous program evaluation (THECB, 2012). Improvements to assessment and placement, particularly of first-time-in-college (FTIC) students, were the seventh goal (THECB, 2012). The eighth goal addressed developmental education practices used with English for Speakers of Other Languages (ESOL) students and supports funding of initiatives and practices to increase ESOL students' success (THECB, 2012). The final goal of the *Statewide Developmental Education Plan* was to better align adult education with postsecondary education, which included developmental education and workforce training (THECB, 2012). The Texas Education Code was amended further to make these nine goals not only part of the plan, but of state policies governing developmental education (3 Tex. Educ. Code § 61.07611, 2017).

The nine goals were addressed in the *2012-2017 Statewide Developmental Education Plan* through five key recommendations. First, acceleration models of developmental education, especially those which are "non-course competency-based, integrated, take advantage of new technologies, and enable successful outcomes," should be scaled (THECB, 2012, p. 3). The second recommendation noted professional development for developmental education faculty and staff should be promoted and funded (THECB, 2012). Third, institutions at which developmental education programs are available should receive sufficient time and opportunity to scale and implement research-based best practices and recommendations (THECB, 2012). Required partnerships should be built among two-year institutions' developmental education, adult basic education, and workforce training programs with family agencies and social services involved was the fourth recommendation (THECB, 2012). The final recommendation of the *Statewide Developmental Education Plan* supported requirements for adult basic education and the incorporation of relevant data into existing statewide data systems (THECB, 2012).

It is worth noting these goals and recommendations were based, in large part, upon the evaluation results of nine developmental education initiatives funded by the THECB (2012). House Bill 1244 of the 82nd Texas Legislature (signed by Governor

Perry on June 17, 2011) was the state's first developmental education plan developed in 2009 and passed in 2011 (Booth et al., 2014). Rider 52 of the bill included funding earmarked for THECB to disburse among developmental education initiatives created to address the *2009 Developmental Education Plan* goal of developing and studying research-based best practices for improving developmental education students' success (Booth et al., 2014). These resources financed the state's Developmental Education Demonstration Projects and were implemented at nine different institutions in the state (Booth et al., 2014; THECB, 2012; THECB, 2014a). The institutions included five community colleges and four universities: Alamo Colleges, El Paso Community College, Lone Star College System, San Jacinto College, Tarrant County College District, The University of Texas at Austin, Texas State University, Texas A&M University-Commerce, and the former University of Texas-Pan American (Booth et al., 2014; THECB, 2012). The funded initiatives addressed five practice areas: assessment and placement, advising, accelerated instruction, faculty development, and alignment between adult basic education and developmental education (THECB, 2013).

In the *Rider 52 Report*, which included results of the initiatives created under the Developmental Education Demonstrations Projects, technology use is noted as playing a "key role across all these areas" (THECB, 2013, p. 6). At El Paso Community College, services to help students prepare for placement testing were delivered through Pretesting/Retesting Educational Program (PREP) which included in-person meetings, online test preparation, workshops, and computer-assisted instruction (THECB, 2013). A PREP Specialist held responsibility for working with students referred to placement testing and interacting with nondevelopmental education students who participated in adult education programs (THECB, 2013). A total of 1,700 students participated in the program and placed at least one level higher in mathematics (57%), reading (58%), and writing (64%) compared to those who did not attend the PREP workshops (THECB, 2013). The results of this intervention supported the development of the fourth goal of the *2012-2017 Statewide Developmental Education Plan*, improving advising and counseling services.

At Lone Star College System, for example, underprepared students requiring developmental reading and developmental writing remediation were placed in a single integrated reading and writing course. Ninety percent of the students who placed in the integrated course successfully passed, and 78% of these students passed the gateway English course afterwards (THECB, 2013). The persistence rates of developmental education students who completed the integrated course were consistent with their nondevelopmental education peers. After two years of consistent results, the remaining separate developmental reading and writing courses were transitioned permanently into the lone integrated course (THECB, 2013). The third goal of the *2012-2017 Statewide Developmental Education Plan*—accelerated developmental education—was informed by the findings of this initiative at Lone Star College System.

Technology was a central piece of two initiatives of the Developmental Education Demonstration Projects. First, an online tutoring program was implemented at Houston Community College to facilitate tutoring in 22 subjects. Evaluation of the redesigned tutoring program indicated that for every unit of tutoring a student sought during a semester, their grade point average increased by .05 points (THECB, 2013). The second example of technology use was an accelerated and hybrid strategy implemented at

Amarillo College. The approach at Amarillo College involved the creation of the ACcess Learning Center to provide an alternative to traditional developmental education courses (THECB, 2013). Rather than enroll in developmental reading, writing, or mathematics courses, students completed first a preassessment to determine their needs. The students subsequently completed a basic academic skills course through the college's Learning Center. Nearly 1,000 students completed the basic skills course in mathematics and 62% of them passed College Algebra with a grade of C or better (THECB, 2013). The findings from technology use at Houston Community College and Amarillo College informed the second goal of the *2012-2017 Developmental Education Statewide Plan*, which was to expand technology use in developmental education.

The *2012-2017 Developmental Education Statewide Plan* was not the first initiative to reform developmental education. In 2009, a report issued by the THECB included six core areas for developmental education reform: innovative program strategies, counseling and academic advising, faculty development, program excellence, assessment and placement, and alignment with Adult Basic Education (THECB, 2009, p. 2). Unlike the *2012-2017 Developmental Education Statewide Plan*, the *Statewide Developmental Education Plan 2010-2011 Biennium* did not include guidance or requirement for technology use in developmental education. Nonetheless, developmental education was changing in Texas, with many public two-year institutions piloting and implementing technology-based solutions to deliver developmental education courses and support developmental education students (Booth et al., 2014).

Statement of the Problem

The *2012-2017 Statewide Developmental Education Plan* concluded in summer 2017, suggesting there was need to study whether the plan was, indeed, successful in achieving the nine stated goals, addressing the five key recommendations, and improving developmental education students' success. The idea of conducting such a study was consistent with research-based best practices in developmental education and aligned with recommendations for formal assessment to ensure developmental education programs meet standards of practice (Boylan, 2002). Lewis (2015) suggested studying program components is essential to delivering effective developmental education. Also supporting this point were Schwartz and Jenkins (2007) who conducted a literature review of practices used in developmental education in community colleges. The researchers found adopting processes to monitor programs and student progress is necessary to ensure successful outcomes for developmental education students (Schwartz & Jenkins, 2007).

Research about developmental education programs and student performance also contributed to decision making (Gerlaugh et al., 2007; Martinez & Bain, 2014). Burns and Schuller (2007) wrote about the role of evidence from educational research and the interaction between research and policy. Educators, leaders, and policymakers must make decisions quickly, but they require sufficient information to advise those decisions (Burns & Schuller, 2007). The authors noted educational research is necessary to bridge the gap between researchers and policymakers to better inform policies and decision making (Burns & Schuller, 2007). Past studies about developmental education in Texas have contributed to state policies and amendments to the Texas Education Code. The

Committee on Testing of the Coordinating Board (1986) conducted a statewide study about student deficiencies in basic skills. The committee's report included seven recommendations for addressing students' lack of preparedness for college courses. One recommendation was to use testing to determine incoming college students' skill levels in reading, writing, and mathematics (Committee on Testing of the Coordinating Board, 1986). The suggestion was implemented later as the Texas Academic Skills Program and amended to the state's education code via House Bill 2182 of the 70th Texas Legislature (Signed by Governor Clements on August 31, 1987; Griffith & Meyer, 1999; Hill & Watson, 1987). Other suggestions included requiring public institutions to provide developmental education courses and programs, and for the state to financially support developmental education efforts (Committee on Testing of the Coordinating Board, 1986). Both recommendations persist in current state higher education policy as evidenced by Senate Bill 162 and House Bills 1244 and 3468 of the 82nd Texas Legislature (Signed by Governor Perry on June 17, 2011) (Research Division of the Texas Legislative Council, 2011).

Senate Bill 162 (Signed by Governor Perry on June 17, 2011) revised Texas Education Code in relation to the state's developmental education plan. Specifically, the state's plans must be considerate of the need to provide effective and efficient developmental education to students; technology must be used to deliver developmental education courses; training must be provided for developmental educators; and ongoing improvement is required of developmental education programs (Research Division of the Texas Legislative Council, 2011). House Bill 1244 (Signed by Governor Perry on June 17, 2011) amended § 51.3062 of the state's education code to define program evaluation, require higher education institutions to use research-based best practices in developmental education courses, and authorized the THECB to establish standards for assessing students' college readiness as well as the instrument used for assessment and placement (Research Division of the Texas Legislative Council, 2011). Additionally, House Bill 3468 (Signed by Governor Perry on June 17, 2011) amended § 51.3062 as well to identify the five types of developmental education options encouraged by the Texas Higher Education Coordinating Board: (a) course-based programs; (b) non-course-based programs including advising programs; (c) modularized programs; (d) competency-based education; and (e) corequisite courses in which students take concurrently a developmental education and college-level course (Research Division of the Texas Legislative Council, 2011).

A third reason for studying developmental education relates to the costs associated with providing developmental education to underprepared students. The field of developmental education has garnered criticism about expenses, noting there were cost inconsistencies among states (Breneman, 1998; Breneman & Haarlow, 1998), doubled costs to state taxpayers (Saxon & Boylan, 2001), and developmental education courses were costly in time and money to students (Venezia et al., 2003). Breneman and Haarlow (1998) estimated developmental education costs to public higher education institutions at $1 billion, a figure updated by Pretlow and Wathington (2012) who estimated developmental education costs have increased 13% to $1.13 billion. Financial estimates in Texas for supporting developmental education are $206 million, an increase of 5.5% over a decade (Pretlow & Wathington, 2012; THECB, 2012).

More recently, Saxon (2017) evaluated state and national studies of the costs of developmental education. Ascertaining the costs of developmental education, Saxon (2017) argued, are made difficult by disjointed accounting models, a lack of consideration for revenues generated by developmental education tuition and other funding sources, and arbitrary figures reported for state developmental education costs. Despite the critics of developmental education costs, the programs curtail costs of social dependence—a point also made by McCabe and Day (1998)—which should be considered “a bargain” (Saxon, 2017, p. 504). Saxon (2017) also recommended developmental education costs should be examined, particularly in response to current trends of reforming developmental education programs to facilitate student success. The point is emphasized within the *2012-2017 Statewide Developmental Education Plan* goal “to serve students who require developmental education in an effective and cost-effective manner” (THECB, 2012, p. 1).

Yet another reason to study developmental education programs was to explore the circumstances of public higher education institutions. The Higher Education Coordinating Act of 1965 was amended by Senate Bill 162 of the 82nd Texas Legislature (Signed by Governor Perry on June 17, 2011) to designate two-year public higher education institutions as principal providers of developmental education programs (Research Division of the Texas Legislative Council, 2011; 3 Tex. Educ. Code § 61.07611, 2017). Additionally, a statement within the *2012-2017 Statewide Developmental Education Plan* and Chapter 61 of the Texas Education Code assigned public two-year institutions with priority for delivering developmental education to help underprepared students improve academically (THECB, 2012). Following the passage of a house bill in 2017, however, Chapter 51 was updated to maintain similar requirements of all higher education institutions at which developmental education is provided (3 Tex. Educ. Code § 61.07611, 2017). Evaluating developmental education, especially in two-year institutions, was consistent with the work of McMillan et al. (1997) who explained that community colleges, in particular, are obligated to exhibit "accountability in student outcomes" (p. 25) when providing developmental education to underprepared students. Capt (2011) noted as well that developmental education is vital to community college missions and contributes to enabling access to higher education. As argued by Bailey and Cho (2010), meeting the needs of underprepared students is "perhaps the most difficult and most important problem facing community colleges," making studies of developmental education in two-year institutional settings all the more essential to delivering effective developmental education programs (p. 46).

The final and, arguably, primary reason for focusing this study on the relationship between technology use and student performance in developmental education was to address a gap in the literature. Many publications included descriptions of strategies for incorporating technology into instructional settings (Cederholm, 2010; David et al., 2008; Engstrom, 2005) and transforming developmental education classrooms into learning labs (Engstrom, 2005; Epper & Baker, 2009; Rutschow & Schneider, 2011; Parisi & Graziano-King, 2011; Williams, 2016). Mahmood's (2006) literature review of technology use in K-12 and nondevelopmental areas of higher education included comparative studies of student performance in traditional and technology-assisted mathematics courses. Several meta-analyses were included and indicated both positive relationships of technology use to improve students' mathematics knowledge and no statistically significant differences in student performance between traditional and technology-enhanced mathematics classes. In developmental education, however, Mahmood (2006) noted that research on the effectiveness of and relationship between technology and student performance could not be located.

Although more literature had been published to address this issue, there remained a research gap on this topic, which is especially problematic because technology use in developmental education is now required by state policy. The technology mandate was issued in the *2012-2017 Statewide Developmental Education Plan*, amended the Higher Education Coordinating Act of 1965, and appeared in House Bill 2223 of the 85th Texas Legislature (Signed by Governor Abbott on June 10, 2017); the latter policy went into effect on September 1, 2017 (Research Division of the Texas Legislative Council, 2011; THECB, 2012; THECB, 2013). Despite favorable findings of technology-enhanced interventions funded through the Developmental Education Demonstrations Projects for supporting online tutoring, early alert systems for advising, and distance education (Booth et al., 2014; THECB, 2013), and support for technology as a best practice in developmental education (Pierce, 2012), whether technology use in developmental education is effective or beneficial remains to be seen (Martirosyan et al., 2017; Saxon et al., 2016).

Purpose of the Study

The primary purpose of this research was to study the use of technology in developmental education instruction—more specifically, the relationship between technology use and student performance in developmental mathematics courses. The study purpose related to the second goal of the *2012-2017 Statewide Developmental*

Education Plan (THECB, 2012). The goal indicated the requirement for public higher education institutions to integrate technology into developmental education courses and programs for purposes of effectiveness and efficiency (THECB, 2012, p. 9). To support the technology mandate, the THECB referenced a literature review conducted by Skidmore et al. (2012) and the Developmental Education Demonstration Projects reported by THECB (2012) and, later, Booth et al. (2014).

The focus on technology was reflected in the first recommendation of the *2012-2017 Statewide Developmental Education Plan* as a suggestion to the Texas Legislature to "take advantage of new technologies" in developmental education (THECB, 2012, p. 3). Both the *2012-2017 Statewide Developmental Education Plan* goal and recommendation continue to take form in state policy, including House Bill 2223 of the 85th Texas Legislature (Signed by Governor Abbott on June 10, 2017) (3 Tex. Educ. Code § 61.07611, 2017). The secondary purpose of this study was to address the literature gap in research exploring whether relationships exist between technology use and student performance in developmental education courses. This focus was also important in Texas because it created evidence consistent with Burns and Schuller's (2007) suggestions for contributing to and informing policymaking, such as the state mandates for technology use in developmental education programs.

Significance of the Study

This research study provided an examination of technology use in developmental education in a public higher education institution located in Texas. This study also explored whether technology use related to outcomes of student performance in developmental mathematics courses. The focus and findings of this study were significant in several ways. First, as argued by Burns and Schuller (2007), lawmakers who create policy to govern education require evidence to inform these decisions. Higher education and, in particular, developmental education in Texas are guided by policies and requirements included in the Texas Education Code and the Higher Education Coordinating Act of 1965, to name a few. Mandates within legal doctrine levy requirements for mandatory placement and assessment of incoming college students, college readiness standards, instructional models or strategies in developmental education (e.g., accelerated and corequisite models), and technology use (3 Tex. Edu. Code § 51.331, 2017). Further, relevant administrative and education codes are amended periodically by house and senate bills signed into law by the acting governor, which provide additional or clarified guidelines to higher education institutions in the state (3 Tex. Educ. Code § 61.003, 2013; 3 Tex. Educ. Code § 61.07611, 2017; Research Division of the Texas Legislative Council, 2011).

The Texas Success Initiative (TSI) is an example of higher education policy affecting developmental education programs (19 Tex. Admin. Code, § 4.51, 2003). The TSI statute appears in both Texas Administrative Code and Texas Education Code beginning with § 4.51 of Subchapter C and § 51.331 of Subchapter F-1, respectively (19 Tex. Admin. Code, § 4.51, 2003; 3 Tex. Edu. Code, § 51.331, 2017). Within administrative code, TSI includes guidelines for students exempt from TSI standards and requirements for institutional assessment of students' college readiness and advising students about their coursework as well as requirements specific to developmental education programs (19 Tex. Admin. Code § 4.54, 2018; 19 Tex. Admin. Code § 4.55, 2018; 19 Tex. Admin. Code § 4.62, 2018). The guidelines were reinforced in relation to developmental education in § 51.336 which includes guidelines for using the Texas Success Initiative Assessment instrument for assessing and placing students in developmental education and college-level courses, and requires institutions to include eight components consistent with research-based best practices of the developmental education field (3 Tex. Edu. Code § 51.336, 2017). As per the Texas Education Code, "An institution of higher education must base developmental coursework on research-based best practices that include the following components: (a) assessment; (b) differentiated placement and instruction; (c) faculty development; (d) support services; (e) program evaluation; (f) integration of technology with an emphasis on instructional support programs; (g) non-course-based developmental education interventions; and (h) subject to the requirements of Subsection (c), course pairing of developmental education courses with credit-bearing courses" (3 Tex. Edu. Code § 51.336, 2017).

Other policies and statewide initiatives affecting developmental education programs included *Closing the Gaps: The Texas Higher Education Plan* and *Comprehensive College Readiness and Success Models for 60x30TX*, often referred to as *60x30TX*. The goals of *Closing the Gaps* primarily focused on improving preparation of students for higher education and the workforce, using developmental education as a vehicle for accomplishing this overarching vision (THECB, 2010). The *Closing the Gaps* plan for higher education concluded in 2016 and was replaced by the *60x30TX Texas Higher Education Strategic Plan* (THECB, 2015; THECB, 2018a). One of the goals of *60x30TX* was to reduce the number of years it takes for higher education students to earn associate's and bachelor's degrees amid estimates of only 53% of all higher education students graduating within six years (THECB, 2015). Like the previous plan, *60x30TX* involved developmental education within the goals. In the strategic plan, higher education institutions were to incorporate approaches like corequisite courses and competency-based programs into developmental education, and must have used technology (THECB, 2015). This study was, thus, significant to contributing to informing strategic plans for developmental education and higher education, and to amending or reviewing state codes and other legislative doctrine.

This study was also significant to addressing gaps in and contributing to the body of research about technology-mediated developmental mathematics. Mahmood (2006) and Saxon et al. (2016) noted difficulties in locating research studies about the effectiveness of technology use in developmental education. Indeed, many studies about technology use in this field provide case study descriptions and recommendations for using technology based on limited samples (Cederholm, 2010; David et al., 2008; Engstrom, 2005; Skidmore et al., 2012). Although filling the research gap will require more than a single study, this research furthered such attempts and contributed to reflection on what the role of technology was—and perhaps should be—in supporting developmental education programs and developmental education students.

This point is supported by Natow et al. (2017) who conducted interviews with leaders of two-year public colleges across the United States to understand reasons for increasing technology integration into developmental education. The authors recommended increases in technology use in developmental education should correspond with technology use in other areas of education and policy. Identifying only five study examples exploring the effectiveness of technology-enhanced developmental education, Natow et al. (2017) suggested the outcomes were mixed at best and required additional study. Ashford-Rowe and Holt (2011) also noted integrating technology into any educational setting should be accompanied by careful decision-making and evidence because too little about the effectiveness of technology in education is known.

Finally, this study contributed to research-based best practices used in public higher education institutions at which developmental mathematics instruction is delivered. The Higher Education Coordinating Act of 1965 was amended by House Bill 1244 of the 82nd Texas Legislature to include a requirement for institutions to ensure best practices guide developmental education programs. The specific requirement identified several research-based best practices as critical to developmental education courses in higher education institutions (Research Division of the Texas Legislative Council, 2011). Moreover, using technology to deliver and support developmental education programs is a required best practice mandated by Texas policy (THECB, 2012; THECB, 2013). Educational researchers also agree with studying educational uses of technology to evaluate effectiveness and further inform best practices. Means et al. (2010) conducted a meta-analysis about online learning used in various areas of education including higher education. The researchers sought evidence about the effectiveness of online learning as well as the factors influencing effectiveness. Means et al. (2010) noted, however, research on technology and practices remain limited and should be broadened by studying theory-based practices.

Additionally, others like Blair (2006) suggested pedagogical standards in two-year public institutions should include specifically technology enhancements to the learning environment. Pierce (2012) found faculty frequently perceived technology as effective and Boylan (2002) noted technology as a recommended best practice in developmental education, when used in moderation. Finally, Martirosyan et al. (2017) reported developmental education instructors' practices and challenges related to technology integration in developmental education courses. For instance, developmental educators reported limitations in technology availability and support at their institutions, preference for traditional teaching methods, and concerns of technology reducing instructional time.

As mentioned previously, purposes of this research included contributing meaningfully to addressing the literature gap in technology use in developmental mathematics courses and studying the relationship between technology use and student performance in developmental mathematics. Miles and Huberman (1994) suggested conceptual frameworks as an important aspect of researching relationships between variables. To guide this research, a conceptual framework combining elements of student involvement theory and the I-E-O model were used.

Conceptual Framework

Conceptual frameworks can provide researchers with guidance in identifying "key factors, concepts, or variables—and the presumed relationships among them" (Miles & Huberman, 1994, p. 18). By using a conceptual framework, the researcher informs their research design and methods for analyzing data (Maxwell, 2005; Miles & Huberman, 1994). Further, defining which variables are meaningful and should be collected for study are facilitated through using conceptual frameworks (Miles & Huberman, 1994). Though other theories and concepts can inform research about developmental mathematics, student performance, and technology use, Astin's (1965, 1991) I-E-O model as a conceptual framework best fit the objectives of this study.

Astin’s (1965) work exploring the effects of college characteristics on students’ career choices is, perhaps, one of the earliest descriptions of what evolved into the I-E-O model. In the study, Astin (1965) defined three types of information—criterion, control, and characteristic—that relate to student outputs, student inputs, and environmental data, respectively. The outputs were defined as students’ career choices, inputs were student characteristics, and environmental data referred to characteristics of the college that were expected to affect students’ performance. Although Astin’s (1965) aim was to explore the relationships between and among these variables using step-wise multiple regression, the model was later adapted to a pilot study of a national research data bank in higher education (Astin & Panos, 1966) and as a model of educational program evaluation (Astin & Panos, 1971). In the latter application, Astin and Panos (1971) redefined the three variables to better fit the nature of educational programs. Specifically, outputs were defined as the objectives of an educational program, inputs were student characteristics—namely, those characteristics with potential for growth and learning—and, rather than environment, the authors referred to *operations* as characteristics of educational programs that were “capable of affecting the relevant student outputs” (p. 736).

The practice of adapting student outputs, student inputs, and environmental characteristics also includes Astin’s (1970a, 1970b) two-part series focused on research methods and designs for studying relationships among and interactions between the three variables, where possible. Again, definitions for the variables incorporated language from prior adaptations, and *environment* was generalized to the *college environment* as characteristics of the institution that affected the student (Astin, 1970a, p. 225). Characteristics capable of affecting the student were broadly defined to include everything in the college environment from administrative policies to facilities to teaching practices and more (Astin, 1970a), well beyond Astin’s (1965) earlier definition reliant upon characteristics affecting student performance.

The formal I-E-O model was then presented by Astin in 1991, having emerged from prior research of how student outcomes were affected by educational inputs and the learning environment and adaptations described above. In this work, students’ personal characteristics, including their family backgrounds, demographics, ages, and socioeconomics, were defined as the inputs. The environment variable was the students’ experiences in education, which was defined by four influencers of student outcomes (Astin, 1991). The four influencers were identified by Astin (1991) as curricular influences, instructional experiences, student experiences outside of the instructional environment, and institutional characteristics. The third component, outcomes, was defined as various academic, occupational, and developmental achievements.

Astin’s I-E-O model was compatible with this study for several reasons. First, the model provided for researching three meaningful components influencing students’ development. In developmental education, students’ development was focused often on facilitating students’ becoming college-ready and gaining academic preparation to take college-level courses. Within the I-E-O model, the three components were interrelated and capable of exerting multidirectional influence on each component (Astin, 1991). Another reason for using this framework was Astin’s (1984) guidance for addressing student development and, especially, working with students facing academic difficulty, which seems appropriate for developmental education students who were deemed underprepared for college-level coursework.

Beyond Astin’s (1970a, 1970b) and Astin and Panos’s (1966, 1971) adaptations, the I-E-O model has been applied in educational research in a variety of ways. For instance, Judd and Keith (2012) suggested treating the components as independent, leaving open flexibility for incorporating only two of the three elements or controlling for one of the variables. Addams (2013), in a publication of the Association of American Medical Colleges, suggested that inputs could deviate from student characteristics, instead using educational inputs of the institution or program. Similarly, Kuh et al. (2010) considered inputs as the student’s role or involvement in their own learning. Other studies highlighted the flexibility and adaptability of the I-E-O model when applied to different educational concept.

For example, Knight (1994) and Umbricht (2012) each used the model to study the time-to-degree completion of undergraduate and first-generation college students, respectively. Miller (2013) studied the culture of assessment in higher education. Strayhorn (2008) investigated how student engagement relates to personal and social learning outcomes. Norwani et al. (2009) researched how the instructional environment could affect learning outcomes. Finally, developmental education-specific applications included Campbell and Blakey’s (1996) study on early remediation and its effect on student success and Keller’s (2011) research on student success in developmental mathematics.

The I-E-O model offered both flexibility and practicality regarding how the inputs, environment, and outcomes are defined and subsequently evaluated. The use of this model as a conceptual framework contributed to evaluating both student performance in developmental mathematics courses and whether relationships exist between technology use in developmental mathematics and student performance. Finally, the use of technology as the environmental variable served to provide further insight into potential relationships to developmental education effectiveness and, on a larger scale, the relevance and role of technology integration as a best practice in designing and delivering developmental mathematics instruction. In this study, the input variable was students' prior knowledge of developmental mathematics as determined by scores earned on the Texas Success Initiative Assessment. This variable was used as a descriptive factor. The environmental element was a descriptive factor of the use of technology in the developmental mathematics courses (i.e., yes or no) and what types of technology were used (e.g., learning management system, modules, commercial software, etc.). Finally, the outcome variable was student performance, defined as whether students successfully completed the developmental mathematics or gateway mathematics course as determined by students' receiving course credit or a passing grade, respectively.

Research Questions

Two research questions guided this dissertation study.

1. How does student performance in developmental mathematics courses relate to the integration of technology in developmental mathematics courses?
2. How does student performance in gatekeeper mathematics courses relate to technology use in developmental mathematics courses?

Delimitations

Delimitations help to define the scope and boundaries within a research study (Creswell, 2014). The researcher's interests in developmental mathematics and technology primarily delimited this study regarding the research questions and study variables, which were both specific to student performance outcomes of developmental mathematics students. This interest was also based on the higher incidence of technology use in developmental mathematics courses, as discovered in reviewing the literature. The researcher's home state of Texas and, more specifically, home institution in southeastern Texas were delimitations. These boundaries were established for several reasons.

As a doctoral student of a developmental education administration program there was a desire—if not a need—to explore avenues of research that would contribute practically and meaningfully to the field of developmental education and research-based best practices. Being both a student and resident of Texas enabled favoritism towards study within the state and university setting; however, the extent to which statutes have been revised to prescribe standards and requirements for developmental education courses and programs made Texas an ideal setting for this research. This delimitation was supported by technology use in developmental education, in particular, becoming an increasingly common element of Texas Administration Code, Texas Education Code, and various senate or house bills used to modify each for purposes of improving developmental education offerings in Texas.

Finally, although this study could have addressed various technology used in developmental education courses and programs, the decision to focus on technology used in developmental mathematics instruction was a further delimitation. In the absence of specific guidelines or definitions for developmental education technology, descriptions provided by Cederholm (2010) and Natow et al. (2020) bound the technology included in this study. Cederholm (2010) defined developmental education technology by type, such as interactive tools like blogs and games, visual tools like PowerPoint presentations, and tools meant to improve teaching developmental education like classroom response systems, or clickers. Conversely, Natow et al. (2020) identified three types of technology and defined these by the purpose of each in developmental education.

Instructional technology was defined as technology used to provide instructional content, which may include commercial software such as ALEKS (Natow et al., 2020). Course management technology referred to electronic systems for organizing class materials and providing them to students; learning management systems such as Blackboard and Canvas were examples of course management technology. Finally, the authors identified student support technology and defined this as technology that provides electronic assistance to students outside of the classroom, which includes online tutoring and early alert systems. Because the focus of this research was developmental mathematics courses, technology was delimited to instructional technology as described by Natow et al. (2020) and included interactive, visual, and other teaching tools described by Cederholm (2010).

Limitations and Assumptions

The primary limitation of this study was that it relates specifically to developmental education in a single public higher education institution in southeastern Texas. Although findings may be comparable to other state or national findings and similar study may be possible of other state’s or Texas’s institutions, there was no guarantee these findings would be generalizable to other settings or studies. The findings of this study provided insights into technology use in developmental mathematics courses in one institution, which may hold relevance to policy makers or researchers engaging in study of this topic in other venues.

Additionally, this study referred to student performance as measured by students' final course grades in developmental mathematics and gatekeeper, college-level mathematics courses. Yet another student performance measure is the scores students earned on the Texas Success Initiative Assessment instrument, the input variable of the I-E-O model, used to identify students' preexisting knowledge of mathematics. These measurements are not the only student performance measures that exist, nor are they the only indicators of student success or effectiveness. Developmental mathematics students and courses may be assessed or evaluated by other measurements, such as grade point averages, rates of persistence, and time to degree completion. Further, while the relationship between student performance and technology use can be studied, any comparison or correlation discovered does not imply causation. In other words, it was not certain that the existence of certain components of developmental mathematics courses, namely instructional technology, was responsible for any observable effects on student performance.

A final limitation of this study related to the source of the collected data. Specifically, the data included student performance outcomes and developmental mathematics course practices involving technology as related to only one university's institutional research office. In this respect, research findings were limited to this setting. Beyond study limitations, several assumptions were made. First, it was assumed all incoming students at the university included in this study were assessed and placed appropriately using the Texas Success Initiative Assessment and policies of the Texas Success Initiative, respectively. It was also assumed that institutional records for student performance and technology used in developmental mathematics courses are accurate and complete.

Definition of Terms

A range of terminology was used in this study that related to technology use and student performance in developmental mathematics. To ensure understanding of these terms used, the following list contained operational definitions for words commonly associated with developmental education, developmental mathematics, and technology as used in this study.

Achievement. In general, this referred to an indication of a student reaching a successful outcome. In the literature on developmental education, *achievement* referred to outcomes like pass rates (Boylan et al., 1992; Hodara, 2013; Kozakowski, 2019; Weisburst et al., 2017; Wladis et al., 2014), number of course attempts before passing the course (Charters, 2013), improvements in pre-post assessment or diagnostic test scores (Edgecombe, 2015; Kallison, 2017), and achieving state-established benchmarks for college readiness.

Best Practices. Research-based standards of practice exist to guide developmental education programs and practitioners in the design and delivery of the courses, programs, and services to aid underprepared students in becoming college-ready (Boylan, 2002; Moss & Yeaton, 2006).

College-Ready. A condition of preparedness for college-level coursework or programs as often determined by student performance on placement assessments (THECB, 2018c), or addressed in various state initiatives in Texas, such as *Closing the*

Gaps: The Texas Higher Education Plan and the *Comprehensive College Readiness and Success Models for 60x30TX*.

Corequisite. A redesign effort for developmental education courses, including in developmental mathematics. The corequisite approach was mandated in Texas as the model required for developmental education courses (THECB, 2018b). Corequisite was also defined in past studies as an approach to concurrently delivering developmental and college-level mathematics content in a single course (Kashyap & Mathew, 2017; Kosiewicz et al., 2018; Mireles et al., 2014; Walker, 2015).

Developmental Education. A field of practice and research related to developmental psychology that is focused on addressing underprepared college students needs in a holistic manner (Casazza, 1999; Schak et al., 2017). Developmental education programs and courses are intended to address students' academic deficiencies in subjects such as reading, writing, and mathematics (Moss & Yeaton, 2006). These programs often feature courses as well as academic support services, such as advising, tutoring, and supplemental instruction (Boylan, 2002; Casazza, 1999).

Developmental Mathematics. Sometimes referred to as pre-college mathematics (Mao et al., 2016), lowest-level mathematics (Xu & Dadgar, 2018), and remedial mathematics (Hagedorn & Kuznetsova, 2016; Kim & Hodges, 2012; Schak et al., 2017; Showalter, 2017). Developmental mathematics focuses on basic- to algebra-level skills for underprepared students. The courses used to relay this content via traditional and corequisite approaches in the institution in which the study is set will be referred to as developmental mathematics courses or developmental mathematics.

Educational Technology. A broad field subsuming related technology, such as instructional technology, learning technology, and e-learning (Reiser & Ely, 1997). Various forms of technology are used in educational settings, ranging from audio and visual media to computers. The field is guided by educational theories and incorporates research and ethical practice (Januszewski & Molenda, 2008).

Gatekeeper. A modifier designating the first college-level course following developmental education coursework. Goudas and Boylan (2012) defined gatekeeper courses as "the typical first-year mainstream course a student takes at any college" often referring to college-level English or math (p. 2). The gatekeeper, college-level mathematics class in this study varied depending upon the first college-level mathematics course required of students based on their major program of study.

Instructional Technology. A field of technology within the broader educational technology context. Instructional technology is used to address instructional problems with solutions through "theory and practice of design, development, utilization, management, and evaluation of processes and resources for learning" (Seels & Richey, 1994, p. 1). Unlike educational technology, the roles of instructional design and media are encompassed by instructional technology for teaching and learning purposes (Anglin, 1995). In this study, instructional technology was defined as the forms of technology used in developmental mathematics courses as determined by the course syllabus.

Pass Rate. This outcome was often used in relation to discussions about student achievement and success. In developmental mathematics research, pass rate was used to indicate a student successfully completed a course (Boylan et al., 1992; Hodara, 2013; Kozakowski, 2019; Weisburst et al., 2017; Wladis et al., 2014) or earned a grade of C or higher in a specified course (Bishop, 2016; Gerlaugh et al., 2007). In this study, pass rate deferred to the grading scales used in the developmental and college-level mathematics courses. The pass rate for developmental mathematics courses was students’ earning credit because the course is graded on a credit and no credit basis. Grading in college-level mathematics courses occurred on a five-point scale ranging from A through F. Pass rate for the college-level courses was defined in this study as students’ earning a C or higher in consistence with the university policy requiring students to maintain a 2.0 GPA, which corresponds to a C average.

Placement. The process by which incoming college students' prior knowledge and skills are assessed. In Texas, a state-approved assessment is administered to students who do not meet exemptions of the Texas Success Initiative, such as prior college-level coursework completed, veteran status, among others. Based upon the score a student earned on the placement assessment, they may be referred to developmental education interventions if they do not meet established cut-scores of benchmarks.

Prior Knowledge. This referred to students' baseline knowledge in a particular subject, which is mathematics in this study. Prior knowledge was defined as the score earned by a student on the state-approved assessment, known as the Texas Success Initiative Assessment (TSIA).

Student Performance. In general, student performance may refer to an outcome related to achievement or success. Student performance may be evaluated by pass rates, course grades, or scores earned on relevant assessments. In this study, student performance was linked to pass rate, which is defined as whether credit was earned for the developmental mathematics course and whether a student earned a C or higher in the gatekeeper, college-level mathematics course.

Success. Success referred to several circumstances across the literature, including students’ pass rates in developmental education or college-level coursework or whether a student met a state standard or benchmark related to college readiness. Also related to achievement, pass rate, and student performance, participants in this study are characterized by success if they achieve student performance determined by pass rates in developmental (i.e., earned credit) and college-level (i.e., earned a C or higher) mathematics coursework. From the literature, students’ performance following completion of developmental education coursework indicated value or benefit to the students’ academic success (Noble & Sawyer, 2013).

Technology-Mediated. A developmental mathematics course was determined to be technology-mediated if educational or instructional technology was integrated to supplement or replace traditional teaching and learning practices. In this study, technology-mediated developmental mathematics involved integration of technological tools as part of the course and identified on the course syllabus.

Texas Success Initiative. Abbreviated TSI, this was an example of higher education policy affecting developmental education programs in Texas (19 Tex. Admin. Code, § 4.51, 2003). The TSI statute established guidelines for exempting incoming college students from mandatory assessment and placement relative to college readiness standards. Students not exempt from the TSI completed a state-approved assessment to compare their scores to established cut-scores to gauge whether developmental education coursework will be required. Other practices outlined in the Texas Education Code focused on research-based best practices to be incorporated into developmental education programs. There were eight components in all, including assessment, faculty development, technology integration, and pairing developmental and college-level courses (3 Tex. Edu. Code § 51.336, 2017).

Texas Success Initiative Assessment. Abbreviated TSIA, this is a state-approved instrument used to assess and place incoming college students in developmental education or college-level courses depending upon how the scores they earn compare to established cut-scores or benchmarks (THECB, 2017c). The TSIA was implemented in Fall 2013 as the official instrument for assessing students' college readiness in Texas.

Underprepared. Unless a student qualifies for an exemption under the Texas Success Initiative (TSI), all entering students at Texas public higher education institutions must complete the Texas Success Initiative Assessment (TSIA) prior to enrolling in college-level courses (THECB, 2016b). If a student did not meet set cut-scores on the assessment, they are considered underprepared for college-level coursework and must successfully complete developmental courses to be deemed college ready (Moss & Yeaton, 2006; THECB, 2016b). In this study, underprepared referred to those students placed in developmental education courses because their performance on the TSIA did not meet the cut-scores established by the state.

Summary and Organization of the Dissertation

In this chapter, an introduction to various elements germane to the dissertation study were presented. A brief background about developmental education and the setting for this study were presented, including relevant policies enacted in Texas to govern developmental education programs. The intention to study technology use and student performance in developmental mathematics coursework was expressed as an approach to exploring whether state policy mandating technology integration in developmental education programs is indeed related to student performance. This study generated evidence about the topic which may contribute to decision making about developmental education and relevant policies. Application of the I-E-O model was also described wherein students' prior mathematics knowledge will serve as a descriptive input variable, the presence of and kinds of technology used will comprise the environmental variable, and students' performance, as defined by whether course credit was or was not received, will function as the outcome variable. The two research questions used to guide this study were identified to explore whether technology use in developmental mathematics courses relate to student performance in the developmental-level course and, subsequently, in the college-level mathematics course.

The following chapter continued with a review to examine literature relevant to this study. More specifically, student performance was discussed in relation to the outcomes of various studies in which student performance was explored. Student performance related to broad definitions of success, including course pass rates and average course grades retention. Program components were discussed in terms of how developmental mathematics programs were designed and delivered to underprepared students, including delivery modes, best practices, and models of developmental mathematics reform and redesign. Finally, the literature review explored technology use in education, including educational and instructional technology and, later, examples of technology-mediated developmental mathematics instruction. Chapter three described how this research will be conducted, including the research questions guiding the study, the participants and data sources used, and how the collected data will be analyzed. The fourth chapter presented the research results and provide answers to the established research questions. The fifth and final chapter included a discussion of the study findings, implications for practice, and suggestions for future research.

CHAPTER II

Literature Review

The purpose of this chapter was to provide background and context to this dissertation study through a literature review. The first part of the chapter was used to provide insight into the literature review process, including descriptions of the search parameters that were applied. Criteria employed for including or excluding pieces of literature are also explained. The chapter then formally progressed into the literature review. The literature review was organized into three primary areas or themes. The first included historical background and context about technology use in education, including definitions for relevant fields and, frameworks for integration. The second was focused on developmental mathematics, including various approaches to instruction and efforts in reform and redesign. The chapter concluded with the third, concentrated on findings and discussion of technology-mediated developmental mathematics. The literature discussed within the three themes also serves as foundation for this study’s application of the I-E-O model. Specifically, the literature enriched understanding of the environmental variable, defined as technologies used in developmental mathematics. Where possible, literature related to the variables for input (students’ prior mathematics knowledge) and outcomes (student performance, both broadly defined and as defined in this study) were presented. Before diving into the literature, here is a brief description of the search process and selection criteria used to conduct the review.

Literature Search Process

The literature search process utilized first the university library's search engine, Engine Orange, to search for available resources. Other databases available through the university were used, including *Academic Search Complete*, *Dissertations and Theses Full Text* (*ProQuest*), *EBSCOhost*, *PsychINFO*, and more. Search terms included *developmental mathematics* or *remedial mathematics* and *technology* or *computer*. This search resulted in nearly 8,886 sources before additional search parameters were implemented. The search was limited further to include results with full text, in English, and with publication dates between 2010 and 2019. Additional inclusion and exclusion criteria helped to narrow down nearly 9,000 results. The final number of publications evaluated for this literature review was 704 before further reduction through inclusion and exclusion criteria.

Inclusion Criteria

The resulting publications were sorted by relevance and the abstracts reviewed in PDF or HTML formats to determine whether the literature would be included in this chapter. For inclusion purposes, results had to be available as full-text in electronic format and were scholarly, peer-reviewed pieces. Within the text, either developmental mathematics or remedial mathematics was mentioned. Technology was also a requirement; specifically, the article had to include discussion of technology as part of a course, model, practice, or study in an educational setting. The technology in question also had to be a part of developmental mathematics learning environments whether the specific technology was described as instructional, educational, or learning technology. Research articles and reports of technology use in developmental mathematics learning environments were not restricted by methods or specific models and practices of developmental mathematics. Further, outcomes could be achievement-related, such as pass rates, findings of affective factors, such as motivation or mathematics anxiety, and more. In as much as possible, included studies were consistent with Astin’s (1991) definitions for inputs, environment, and outcomes as will be used in this study’s application of the I-E-O model. It must be stated, though research articles comprise the bulk of this literature review, nonresearch articles and other academic or government reports were included, especially to provide background or for contextual purposes. Similarly, newer articles were prioritized in the search parameters, but publications earlier than 2010 were included for background and context.

Exclusion Criteria

Search results not included in this literature review were those not available as full-text or in English. Further, results that were not peer-reviewed were excluded; however, research and nonresearch pieces were included, while news and opinion pieces were not. Though some results included mention of or keywords related to technology and developmental education or developmental mathematics, many were tangent to the focus of this dissertation, such as technology use in advising or placement of developmental education students. The search phrase *developmental education* also returned many articles related to primary and secondary education, developmental psychology, and child development; these publications were not included in the literature review. *Technology education* was another related phrase appearing in a considerable number of search results. These results were frequently unrelated to incorporating technology in educational, let alone developmental educational settings, thus these articles are not included. Another round of review resulted in excluding results that were not academic journals, reports, or dissertations and theses. Upon further restricting these results to scholarly, peer-reviewed literature, 704 results resulted.

Supplemental Searches

After narrowing down the literature, supplemental searches were performed. The first search was to obtain background on and definitions for technology in learning environments. Search terms included *instructional technology*, *educational technology*, *learning technology*, or *e-learning* and *definition*, *define*, *meaning*, or *description*. A second supplemental search included phrases about technologies gleaned from the initial search, such as computer-aided or -mediated, technology-mediated or -enhanced, online, distance, hybrid, calculator, learning or course management system, social media, MOOC, media, adaptive learning, learning software, and even specific platforms like Assessment and Learning in Knowledge Spaces (ALEKS) and MyMathLab. For background purposes, the types of literature included in the supplemental searchers were broader, including books and definitions from professional organizations found in conference proceedings or websites. After this search process, the literature was organized into the three themes: background on technology use in education, developmental mathematics learning environments, and research about technology integrated into developmental mathematics.

Background on Technology Use in Education

The first theme was used to present literature on technology as used in the broader educational context. Relevant fields of technology were identified and defined. Distinctions between the fields were made and addressed what technology is included in each. Some background on how technology came to be used and defined in education was also offered. Starting with a brief history of technology use in education, definitions for *educational technology*, *instructional technology*, *learning technology*, and *e-learning* were provided to highlight the interchangeable use of the terms across the literature despite their differences.

Historically, technology in education has been described as whatever is innovative at the time (Reiser & Ely, 1997). Much of the literature and accounts of technology use in education focused on digital varieties, but the earliest technologies existed well before their emergence. Some of these earlier technologies included the abacus, which aided in mathematical calculations and originated in the seventh century (Sugden, 1981), and the Pressey Machine used in the early 1900s to drill and test students on classroom lessons (Pressey, 1926). Movements in the development of visual and audiovisual media (Reiser & Ely, 1997) and significant developments in technology systems, such as the computer and Internet (Cox, 2013), also contributed to modern-day technology seen in educational settings.

Perhaps one’s idea of technology use in education was the application of electronic or computerized tools, instruments, media, or practices. Indeed, much of the relevant literature focused on web-based software (Kinney & Robertson, 2003; MacDonald & Caverly, 1999; MacDonald, Vasquez, & Caverly, 2002), learning management systems (D. Kim, 2017; Natow et al., 2017), social media (Albayrak & Yildirim, 2015; Ingalls, 2017), and scientific or graphing calculators (Aguilar, 2008; Mao et al., 2016; Pape & Prosser, 2018). Even the U.S. Department of Education (2019) identified technology in educational settings as supporting teaching and learning through digital tools like computers and references online learning and open educational resources, while Chen et al. (2018) defined in their study technology as the use of digital media. However, technology, in its purest form, refers to “systematic […] techniques and principles” used “to achieve an objective effectively and efficiently” (Dey, 2017, p. 6), and included overhead projectors (Dey, 2017), chalkboards, books, and any instrument or tool used to accomplish some type of work, including teaching or learning (Hickman, 1990; Moore, 2006).

Notably, Rowntree (1975) cautioned against restricting technology definitions to “electronic gadgetry” (p. 1), an argument also shared by Collier (1977) and Dey (2017), just as Moore (2006) reminded of early definitions of educational and instructional technology (Richey & Seels, 1994; Seels & Richey, 1994) as intentionally omitting references to digital tools. As others described, however, digital-based technology has become the norm in educational experiences (Henrie et al., 2015), and have empowered students, especially in mathematics (Garrett, 2010; Garrett, 2014). This dissertation study acknowledged that face-to-face, hybrid, and online developmental mathematics settings likely involved some form of analog technology. Thus, the focus of this study and literature review was on digital technology, including computer- or electronic-based types, and media or multimedia housed on or delivered through digital technology, such as podcasts, web resources, and videos, in concord by definitions used by scholars (Chen et al., 2017; Coscia, 1999; Reiser & Ely, 1997). Mostly, the attention paid to *digital* technology resulted from the abundance of literature on the subject. Nevertheless, it was also informed by extant terminology explained by various authors and professional organizations.

Foremost, it must be stated that no universal definition exists for technology concerning educational use. While additional and even lesser-known phrases may be used, two primary terms were found in the literature: *educational technology*, *instructional technology*. Other terms identified, but not subject to lengthy discussion in this review are *learning technology*, and *e-learning*. Although some authors used the phrases interchangeably, each term is defined individually by scholars and professional organizations alike. In some cases, phrasing has lent to movements and, in other cases, encompassed entire fields of study and practice (Seels & Richey, 1994). Discussion of the definitions related broadly to education, with particular references to higher education and, sometimes, developmental education.

Educational Technology

Reiser and Ely (1997) explained *educational technology* is a general term that incorporates adjacent phrases like *instructional technology* and *learning technology,* among others. Educational technology is broad and exists as a field of its own, having emerged several centuries ago. Russell (2006) noted educational technology includes “slates, hornbooks, blackboards, and books” (p. 137). As technology evolved, films, computers, and the Internet entered the classroom (Chen et al., 2017; Russell, 2006). In some ways, the field of educational technology has been defined based on how—and what—technology is used. For instance, the visual instruction movement featured heavily visual aids originating in materials collections with museums, such as the St. Louis Educational Museum (Reiser & Ely, 1997). This movement included films, pictures, and lantern slides (Reiser & Ely, 1997; Saettler, 1990), which were considered “essential tools of instruction” (Hoban et al., 1937, p. 121). During the early 1900s when the visual instruction movement began and, later, in the 1920s and 1930s when *visual* instruction shifted morphed into the *audiovisual* instruction movement, however, *educational technology* had yet to be defined.

Between the mid-1940s and 1960s, technological changes took shape in American industry and work (Saettler, 1990), just as leaders of the audiovisual instruction movement increasingly became interested in defining the field. As a result, the Commission on Definition and Terminology was formed by the National Education Association and charged with establishing the definition of *audiovisual communication* (Reiser & Ely, 1997). The resulting definition explained *audiovisual communication* was "the branch of educational theory and practice concerned primarily with the design and use of messages which control the learning process" (Ely, 1963, p.17). As shared by Reiser and Ely (1997), movement leaders again contributed to the evolving terminology, using *educational technology* and *instructional technology* interchangeably with *audiovisual communication*, but some, such as Finn (1960) and Lumsdaine (1964), went beyond the official definition and incorporated *process* and *science* as critical components. *Instructional technology*, as explained by Finn (1960), was for reviewing instructional problems and identifying solutions, while *educational technology* was a method for applying science to instructional practice (Lumsdaine, 1964).

By the early 1970s, however, the professional organization of the field—the Department of Audiovisual Instruction—was now the Association for Educational Communications and Technology (AECT), and required a new definition (Reiser & Ely, 1997). This time, *audiovisual communication* became *educational technology*. Ely (1972) wrote the new definition on behalf of the professional association:

> Educational technology is a field involved in the facilitation of human learning through the systematic identification, development, organization, and utilization of a full range of learning resources and through the management of these processes. (p. 36)

The 1977 definition grew again, this time to ascertain educational technology as complex and for use in "analyzing problems and devising, implementing, evaluating, and managing solutions" (AECT Task Force on Definition and Terminology, 1977, p. 1). In these definitions, perhaps because of their determination by a commission of a professional association, the focus was on defining the field and its role in facilitating learning. However, others were concerned with describing *educational technology* for its role in pedagogy and theory (Ford & Lott, 2009; Ouyang & Stanley, 2014), and as encompassing both teaching and learning (Januszewski & Molenda, 2008; Tripathi, 2019). The scope of educational technology, wrote Januszewski and Molenda (2008), includes "research and ethical practice," is concerned with "technological processes and resources," and "emphasizes communication skills and approaches to teaching and learning through the judicious use and integration of diverse media," (p. 1). Tripathi (2019) also connected educational technology to teaching and learning but concerning psychological principles. More precisely, Tripathi (2019) stated educational technology modifies the teaching-learning process by incorporating many types of teaching "presentation, control, and feedback," (p. 12).

Ford and Lott (2009) argued educational technology feeds into constructivist pedagogy, especially in how it can catalyze knowledge construction and pedagogical change, and enhances activity theory via virtual classrooms, social constructivism through collaborative processes of learning via online social interaction, and situated learning by enhancing learning contexts. Similarly, Ouyang and Stanley (2014) linked educational technology to the development of technology-related educational theories, such as cognitive flexibility theory (Spiro et al. 1988; Spiro et al., 1987), experiential learning theory (Kolb, 1984), and more, expanding upon “major educational theories such as behaviorism, cognitivism, constructivism, and multiple intelligence” (p. 161). In the evolution of *educational technology* through definition, Seels and Richey (1994) revisited the issue, shifting the previous AECT official definition to focus on *instructional technology*.

Instructional Technology

Even before the 1994 definition of *instructional technology* was published, technology used in teaching and learning was commonplace in education. The field’s foundations are the same as *educational technology*, reaching back to the early 1900s in school museums and visual exhibits (Reiser & Ely, 1997) and continues to evolve through applications of the computer, Internet, and both media and nonmedia tools (Gagne, 1987; Reiser, 2001a). Educational technology is the broad framework in which instructional technology resides, and both link with learning theories of behaviorism, cognitivism, and constructivism (Seels & Glasgow, 1998). Seels and Richey (1994) wrote the AECT’s first definition of instructional technology, referring to it as “the theory and practice of design, development, utilization, management, and evaluation of processes and resources for learning” (p. 1). This definition does not appear to be a dramatic departure from the association’s 1972 statement on *educational technology* (Ely, 1972); however, Seels and Richey’s (1994) definition identifies five domains of instructional technology. These domains—design, development, utilization, management, and evaluation—relate to newer theories and practices identified by Gagne (1965, 1985) and include assessment (Glaser, 1963) and evaluation (Scriven, 1967). Further, instructional technology, it is explained, is distinct from educational technology because it also encompasses instructional media and instructional design (Reiser, 2001a; Reiser, 2001b).

Media has been a part of instruction for many decades. It has been low-tech and analog and high-tech and digital, remaining a vital element of instructional technology (Reiser, 2001a). Digital media from the first half of the 20th century included films, audio recordings, slides, and more, and were shaped by the previous visual and audiovisual instruction movements, World War II efforts to develop training materials for military service, post-war research on audiovisual media, and the use of television in instruction (Lumsdaine, 1963; Reiser, 2001a; Saettler, 1990). As interest in instructional television waned in the 1960s, media shifted in response to the first applications of computer-assisted instruction (CAI) via adaptive teaching machines in selected public schools and universities (Reiser, 2001a). The computer in education, however, exhibited little effect, but as computers became readily available to the public in the 1980s, this changed (Pagliaro, 1983). By the mid-1990s through the early 2000s, the role of computers and digital technology exploded, primarily, because of the Internet (Reiser, 2001a). Indeed, media are used now more than ever in instruction, not just in education but in training for business and industry (Reiser, 2001a) and human resource development (Demps, 2008). Media, however, is but one facet of instructional technology. To understand better what instructional technology is and how it is used in education, one also must explore instructional design.

The five domains uttered in the 1994 definition of *instructional technology* bridge theories and practices that have given way to models and frameworks of instructional design. Anglin's (1995) work offers recommendations for how instructional technology can be used in education; however, instructional design serves as its precursor, requiring instruction to be developed and incorporate technology in productive ways. Procedures for designing instruction have been used for more than five decades, and include systems approaches, instructional systems design, and others, tracing back to World War II (Dick, 1987; Reiser, 2001b). During the war, psychologists and educators were tasked with developing military training. To accomplish this, they incorporated their knowledge of psychological theories of human behavior, backgrounds in research and theory on teaching and learning, and expertise in evaluation and testing (Reiser, 2001b). These elements culminated in the programmed instruction movement wherein instruction was encouraged as a process for solving educational problems, and later incorporated behavioral objectives proposed by Bloom et al. (1956) (Reiser, 2001b).

Glaser's (1963) work in the criterion reference testing movement advocated for assessing students' entry-level behavior and Scriven's (1967) development of formative evaluation to address deficiencies in math and science education in the U.S. also took shape. Gagne (1965, 1985) developed five domains of learning outcomes—verbal information, intellectual skills, psychomotor skills, attitudes, and cognitive strategies—providing further foundation to instructional design models. Some of these models include ADDIE, an example of instructional systems design (Branson et al., 1975), universal design for instruction (Burgstahler, 2015), and the Dick and Carey (1978) systems approach model. Even more, scholarly journals and graduate programs in instructional design have emerged (Reiser, 2001b).

The AECT would later report a revised definition, returning to a focus on *educational technology,* leaving the 1994 definition of *instructional technology* unchanged: “Educational technology is the study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources” (Januszewski & Molenda, 2008, p. 1). Instructional technology, the association explained, remains a subset of the educational technology concept and sensitive to the five domains. Nevertheless, instructional technology remained subject to criticism. Moore (2006) argued the field definitions focus on what teachers do to promote learning, ignoring that learners also contribute to their knowledge construction. Others, like Bradshaw (2018), suggested the field must evolve to be more socially just because, historically, instructional design and technology have reinforced structures littered with inequity, injustice, and oppression. Still others voiced concern with the interchangeable uses of *educational technology* and *instructional technology* (Gagne, 1987; Januszewski & Molenda, 2008), adding to the list phrases like *learning technology* (Association for Learning Technology, 2018; Rist & Hewer, 1996) and *e-learning* (Holmes & Gardner, 2006; Katuk et al., 2013).

Rist and Hewer (1996) and the Association for Learning Technology (2018) defined learning technology as being applied to enhance teaching, learning, and assessment, and involving computers, networks, and communication systems. Phrases associated with *learning technology* include computer-aided and computer-based instruction, terms also seen in the literature on developmental mathematics which will be discussed further (Rist & Hewer, 1996). Comparably, *e-learning* is shortened from the phrase *electronic learning* and refers to computer-based learning used in both higher education and professional training environments (Katuk et al., 2013). In Holmes and Gardner's (2006) book, e-learning was defined as "online access to learning resources, anywhere and anytime," (p. 14), and Polczynski (2013) noted it includes asynchronous and synchronous online communications. Unlike definitions of educational and instructional technology, learning technology and e-learning are focused more so on approaches to incorporating computers and the Internet into learning environments. Finally, there are others, such as Henrie et al. (2015), who shared more than ten terms associated with technology use in education. These terms, including *blended learning, distance education*, and *virtual classrooms* (Henrie et al., 2015), were not discussed here but will be presented with practices in developmental mathematics.

Frameworks for Technology Integration

Beyond definitions relevant to technology, frameworks, and practices have emerged to guide technology integration in educational settings. One example came from a text containing 11 recommendations for instructors seeking to use technology for learning. In the book, Stoner (1996) offered a seven-stage life cycle model as a conceptual framework based on systems analysis and design methods. Initiation was the first stage and prescribes preliminary assessment of a problem or opportunity, followed by analysis and evaluation, technology selection, design, implementation, monitoring and adaptation, and concludes with evaluation of process (Stoner, 1996). Throughout the cycle, Stoner (1996) advocated for engaging in quality assurance and considering how technology engaged students' motivation. Their motivation, Stoner (1996) argued, is vital because those who are unmotivated are unlikely to learn and will not benefit from the positive effects of technology.

Another conceptual framework came from Knowlton and Simms (2010), who focused on reaching adult learners through instructional technology. Their approach built upon the curvilinear instructional design model crafted by Morrison et al. (2004), which provided flexible strategies related to learners' role in constructing knowledge. Knowlton and Simms (2010) adapted the model to fit the needs of adult learners, focusing mainly on developmental education instructors and students. The authors recommended using computers for web-enhanced and online developmental education curricula, suggesting benefits in using online discussion boards and communication tools (Knowlton & Simms, 2010).

In addition to these frameworks, others like Ouyang and Stanley (2014) connected educational theory with technology integration via the Blackboard platform for distance education. Just as leaders in the educational and instructional technology fields, Ouyang and Stanley (2014) described the inherent ties between technology use and cognitive, behavioral, and constructive theories. They also linked Gardner's (1983) multiple intelligence theory to possibilities for tailoring teaching strategies and the learning environment as individualized instruction, which could include. In describing features of Blackboard, Ouyang and Stanley (2014) noted several benefits, including collaborative learning and stronger interactions between teachers and students as well as students with their peers. The authors concluded more research is necessary to inform and optimize applications of technology because learners have different learning needs, a conclusion also reached by Chen et al. (2018). Despite high-tech developmental in educational technology and more research of such applications, Ouyang and Stanley (2014) noted theories to appropriate guide technology integration are insufficient, and Chen et al. (2008) argued learners' motivation must also be considered when integrating and studying technology in education. As the literature review now turns to discussion of developmental mathematics practices and, later, technology-mediated developmental mathematics, the other definitions and frameworks will be referenced where applicable.

Developmental Mathematics Practices

In the literature, developmental mathematics is sometimes referred to as pre-college mathematics (Mao et al., 2016), lowest-level mathematics (Xu & Dadgar, 2018), and, more frequently, remedial mathematics (Hagedorn & Kuznetsova, 2016; Kim & Hodges, 2012; Schak et al., 2017; Showalter, 2017). Courses in this subject are provided to developmental education students, more specifically, to those students considered underprepared for college-level mathematics instruction (Mulvey, 2008). Before diving into the literature on this theme, it is worth revisiting the background on and exploring a bit about the educators and learners who participate in developmental education.

Developmental Education

As described in chapter one, the field of developmental education was built upon key aspects of developmental psychology (Casazza, 1999; Schak et al., 2017). Yet, the roles and responsibilities of developmental education continue to change and evolve (Higbee & Dwinell, 1999). Even the field's name, *developmental education*, has not been consistent since its founding. Indeed, developmental education is also referred to as *remedial education*, a name that has carried with it much controversy and stigma for learners and instructors alike, and it has been subject to bias and obsolescence—that is, perceived obsolescence as critics have argued developmental education is unnecessary or ineffective (Datray et al., 2014; Diel-Amen & Rosenbaum, 2002; Higbee et al., 2005; Melguizo et al., 2011). Other related names include *precollege* (Hagedorn & Kuznetsova, 2016; Kadhi, 2004; Zientek et al., 2018), *preparatory* (Clowes, 1980; White et al., 2010), and *compensatory* (Arendale, 2005; Clowes, 1980) when referring to courses or programs for the students deemed not quite college-ready. At its core, however, developmental education is about holistically supporting and educating students who are considered underprepared for college or university coursework (Arendale, 2002; Boylan, 2002; Lundell & Collins, 1999).

Developmental education interventions included applications of theory and best practices (Boylan, 2002; Higbee et al., 2005; Lundell & Higbee, 2001). Boylan (2002), for instance, wrote a book containing 31 research-based best practices for effective developmental education programs. Many of these practices refer to organizational, administrative, and institutional activities, such as how best to centralize or coordinate the courses and services and the need for clear missions, goals, and objectives to guide the programs (Boylan, 2002). Program-specific elements are also addressed, including requiring assessment and placement for entering college students, evaluating the programs, and addressing adjunct faculty roles in developmental education. Boylan (2002) concludes the book by focusing on instructional practices; supplemental instruction, learning communities, and active learning are a few instructional practices discussed.

Of note, Boylan (2002) addressed technology as having potential for supporting supplemental instruction, suggesting “computer graphics, PowerPoint slides, and a variety of other computer applications" warrant consideration (p. 61). More directly, Boylan (2002) recommended technology be used in moderation based upon past studies' findings of diminishing pass rates related to increased computer technology use (Boylan et al., 1992). The tips provided for technology use in developmental education include, "pedagogy is more important than technology" (Boylan, 2002, p. 64), and despite the proliferation of technology across society, many people remain "technologically illiterate" (Boylan, 2002, p. 65). Consistent with discussions of educational and instructional technology, Boylan (2002) stated computers are not the only form of technology, adding audio and video as other options. Beyond the practices employed in developmental education, it is necessary to understand those who participate in these settings. Characteristics of developmental education students, especially affective factors, often are explained or studied in research of technology-mediated developmental education, including in developmental mathematics.

Developmental Education Participants

Developmental education instructors include full-time and, increasingly, adjunct faculty who teach developmental courses (Boylan, 2002; Datray et al., 2014; Saxon et al., 2015) and administrators and staff involved in providing support services to this population of students (Booth et al., 2014; Munsch et al., 2015). Those who teach developmental education courses are present in the literature for both their vital role in ushering underprepared students toward college readiness and limitations given the growing frequency of adjunct faculty tasked with teaching developmental education courses (Datray et al., 2014; Saxon et al., 2015). While much research and practice in this field relate to what occurs in the learning environment, the resources available to developmental education students are contributing elements as well. Keeping consistent with a desire to holistically support and prepare underprepared students, support services found on college campuses are essential (Booth et al., 2014; Milliron et al., 2017; Stern, 2001). Researchers have noted in past studies that mandatory placement and advising (Boylan, 2002; Boylan et al., 1992; Booth et al., 2014; Saxon & Morante, 2014), early alert systems (Booth et al., 2014; McCabe & Day, 1998; Natow et al., 2017), supplementary instruction (Booth et al., 2014; Ramirez, 1997), and services targeted to veteran (Stephens, 2001), nontraditional (Enright, 1995; Van Horne, 2009), and first-generation college students (Hamilton, 2011; Van Horne, 2009) have an effect on or relationship to the college readiness, performance, and success of developmental education students.

Educators represented only one participant group in developmental education, while learners comprised the other. Developmental education students were typically referred to as such because of definitions or policies established by state lawmakers (THECB, 2014; Zientek et al., 2018) and as determined by scores earned on assessment instruments (Showalter, 2017; Saxon & Morante, 2014). In Texas, the setting for this study, students directed to developmental education programs are those who do not meet college readiness standards in reading, writing, or mathematics and were, thus, not in compliance with the Texas Success Initiative (TSI) (THECB, 2017c; THECB, 2018a). College students may bypass developmental education courses if they meet any of the seven exemptions established by TSI. The exemptions included students' meeting or exceeding set scores on ACT or SAT entrance exams, serving in the military, and transferring from another institution at which the student completed college-level coursework (THECB, 2017c). If a student was not exempt under these conditions, they must take the TSI Assessment (TSIA), a test used to determine their college readiness by comparing earned scores to state-established benchmarks (THECB, 2017c). As the THECB (2017c) explained, students who do not meet the benchmarks in one or more subjects are referred to developmental education options, which may include semester-long courses, corequisite courses, non-course competency-based options (NCBO), or modular and technology-based interventions (p. 2).

Backgrounds among the students referred to developmental education also vary; for instance, they may be considered traditional or nontraditional college students. For example, nontraditional students included those who are older, have a disability, are veterans, and have family or work responsibilities (Hagedorn & Kuznetsova, 2016). Still others are characterized as being at-risk or at the lowest-skill-level (Mulvey, 2008; Visher et al., 2017; Xu & Dadgar, 2018), or called adult learners (Pelletier, 2010; Tennant, 2014) and first-time-in-college (FTIC) students (Abraham et al., 2014). Another characteristic of developmental education students in Texas was they were more likely to attend two-year colleges than four-year universities. Indeed, state data indicated 42.6% of first-time college students were not college-ready; broken down this was attributed to 61.0% of two-year college students and 17.7% of university who did not meet standards for college readiness (THECB, 2018c). The various characterizations of developmental education students were noticeable in the literature and appeared in research conducted with developmental education students of particular backgrounds or concerning affective factors; these descriptions were shared, where relevant, as discussion turns to exploring developmental mathematics learning environments.

Relevant Practices, Theories, and Models

Interventions in developmental mathematics focused on transferring basic- to algebra-level skills to underprepared college students (Bahr, 2012). Students referred to developmental mathematics programs may also be underprepared in reading and writing or may lack college readiness only in mathematics (Armington, 2003). Findings from past studies indicated more underprepared students required preparation in mathematics (Armington, 2003; Attewell et al., 2006) and were less successful in mathematics courses when compared to other developmental education subjects (Bahr, 2010; Bonham & Boylan, 2011). Exploration of developmental mathematics began with discussion of traditional and redesigned approaches, including descriptions of specific models and practices reported in the literature. This discussion further laid foundation for exploring the findings of studies on technology integration in developmental mathematics courses.

Traditional and Redesigned Approaches

Developmental mathematics curricula are delivered in several ways. One option featured one or more levels of coursework or module and is often referred to as the traditional approach or, what Higbee et al. (2005) refer to as the prerequisite acquisition model, given the prerequisite nature of developmental education courses. This model may include multiple developmental mathematics courses depending upon the level of remediation needed by a student. Bailey (2009) found students may take as many as three levels of courses, Parsad and Lewis (2003) identified four-year institutions had an average of 2.5 and two-year colleges had about 3.4 courses in developmental mathematics, and Meek (2019) reported students entering with less than high school level mathematics skills would require four separate courses. In terms of credit hours, Bonham and Boylan (2011) explained a student placed at the lowest level of developmental mathematics would have to take “approximately 10 hours of mathematics courses before even having an opportunity to attempt college-level mathematics” (p. 14).

Bailey (2009) voiced similar concerns, noting the low pass rates of students enrolled in traditional developmental mathematics course sequences. Among students enrolled in developmental mathematics courses, about 30% of them pass (Attewell et al., 2006; Bailey, 2009; Bailey et al., 2010). Additionally, students entering college at three levels below the college level passed all three courses 16% of the time (Bailey, 2009). An explanation offered by Edgecombe (2011) for the low percentages is traditional course sequences of developmental education allow too many exit points for students. For instance, students may never enroll in the developmental education courses in which they are placed or may leave the institution between courses in the traditional sequence (Edgecombe, 2011).

The traditional approach has been subjected to other criticisms. With many students needing more than one level of developmental mathematics coursework, especially for those assessed as having the lowest math skills, time and cost are common concerns. Saxon and Martirosyan (2017) noted traditional courses require a greater time commitment compared to accelerated approaches, and Charters (2013) found the emporium model of developmental mathematics reduced the time spent and number of courses taken by students compared to traditional course sequences. Conley (2007) reminded, as more courses are required, a student’s time to college completion is also extended. Indeed, taking two or more levels of developmental mathematics courses, each a semester-long, could add an extra year or more to a student’s college tenure.

Mulvey (2008) explained developmental education is an expense for higher education institutions and students, which is especially precarious because this population of students disproportionally comes from lower socioeconomic backgrounds. Martinez and Bain (2014) also explored the costs of developmental education at the federal and state levels. Citing ACT (2005), Brothen and Wambach (2004), and Phipps (1998), the authors reported the costs range from $1 to $2 billion. Cohen and Brawer (2003) noted most developmental education expenses are paid by states, and Breneman (1998) explained community colleges spend more on developmental education than universities. In their 2001 study, Saxon and Boylan (2001) reviewed several cost studies and found state spending on developmental education is, on average, less than 10% and, in most cases, only 1% to 2%. Saxon (2017) affirmed this finding upon reviewing several national- and state-level cost studies, also stating efforts to reform and redesign developmental education will likely reduce these costs further.

Amid the various criticisms, movements to reform developmental education, and, of importance here, developmental mathematics have been undertaken. Germane to this dissertation study, traditional course sequences for developmental mathematics instruction have and continue to transition to new approaches, many of which incorporated technology. These reforms included shortening traditional course sequences, developing non-course-based options, and establishing new models of teaching mathematically underprepared students. Learning environments in developmental mathematics still included face-to-face options, but are also hybrid (Chekour, 2017; Raju et al., 2018), online (Acosta et al., 2016; Bissell, 2012; Martin et al., 2017), and massive open online courses (MOOCs) (Hernandez et al., 2019). Courses were often accelerated

(Bishop et al., 2018; Kallison, 2017; Walker, 2015; Weisburst et al., 2017), compressed (Cafarella, 2016; Hodara, 2013; Walker, 2017), corequisite (Kashyap & Mathew, 2017; Mireles et al., 2014), and modularized (Ariovich & Walker, 2014; Bickerstaff et al., 2016; Edgecombe, 2016).

New models were called Math Emporium or, simply, emporium (Kozakowski, 2019; Twigg, 2011), Carnegie Math Pathways (Merseth, 2011; Yamada et al., 2018), and the Dana Center Mathematics Pathways (Altstadt et al., 2014; Rutschow et al., 2017), just to name a few. With regard to the study setting, reform efforts have been pursued, as seen in those developed under the auspices of the Developmental Education Demonstration Projects, mentioned briefly in the previous chapter (Booth et al., 2014; Mireles et al., 2014; THECB, 2014) and changes to state policy requiring adoption of corequisite methods (THECB, 2018b). The numerous efforts to reform and redesign developmental mathematics were discussed further alongside relevant research findings.

Hybrid, Online, and MOOC Delivery Modes

Developmental mathematics courses have expanded to include hybrid, online, and MOOC modes beyond face-to-face approaches. Hybrid course delivery involves blending face-to-face instructional practices with computer-aided instruction (CAI), which may involve using computer software to assign homework and tests or delivering study materials and feedback to students (Chekour, 2017). A benefit of the hybrid format presented by Chekour (2017) is it blends “a variety of tools and features to promote students’ understanding of math topics,” which may increase students’ “motivation and contribution to the learning process,” (p. 24). Raju et al. (2018) explained the hybrid approach as assimilating the synchronous modes of traditional classrooms with asynchronous aspects of online learning. Rather than replacing the course with a virtual classroom, students retain face time with their instructors. Raju et al. (2018) studied a hybrid learning environment in which ALEKS, a technology using artificial intelligence to assess students before individualizing their study materials, was used

Several advantages to using ALEKS in a hybrid manner were identified, including students’ ease of accessing and asking questions and instructors’ receiving more efficiently data about how students were performing (Raju et al., 2018). Unlike hybrid approaches, online course delivery shifts away from face-to-face to virtual environments. In this delivery mode, sometimes referred to as *distance education* or *distance learning*, students do not have in-person interactions with instructors or peers, and they often participate in courses using platforms like Blackboard (Ouyang & Stanley, 2014; Raju et al., 2018). Acosta et al. (2016) explored student performance in college-level mathematics after students completed a two-course sequence in developmental mathematics. Three variables were used as predictors for students’ performance, one of which was whether the student completed the developmental mathematics courses face-to-face or online. Of the 290 students included in their study, 17.2% completed the courses online (Acosta et al., 2016). The researchers found GPA was a predictor for students’ earning a C or better in the college-level mathematics course, but delivery mode was not (Acosta et al., 2016).

Conversely, Bissell (2012) reported positive outcomes from pilots of online developmental mathematics courses, including improvements in students’ self-reported attitudes and perceptions of improving their math skills. Instructors also reported feeling the online course was well designed and easy to use (Bissell, 2012). The online courses featured open educational resources, which are freely available resources for teaching and learning, and incorporated video presentations, interactive math problems, textbook readings as well as supplementary resources via interactive tutoring videos, puzzles, and games (Bissell, 2012). In a study published by Martin et al. (2017), the online curriculum employed in developmental mathematics came from a textbook publisher and included online course materials and course management software. As part of the courses, students completed homework, quizzes, and tests online. The authors analyzed data collected from nearly 1,000 institutions to determine content areas commonly featured in the online materials. Martin et al. (2017) found students received the most instruction on number sense, symbolism, and algebra (Martin et al., 2017).

However, another delivery mode found in the literature was the MOOC, an online method of providing education to many learners on platforms like Coursera, edX, Open edX, and Udacity (Boatman, 2014; Hernandez et al., 2019). Like the hybrid approach, Hernandez et al. (2019) described the model for MOOCs in developmental mathematics as aimed at complementing face-to-face courses with digital tools rather than replacing them. The authors' rationale for integrating MOOCs with developmental mathematics referenced past studies indicating increased course attendance by and engagement from students (Hernandez et al., 2019). Students who actively used the materials provided in the MOOCs earned statistically significantly higher average scores in the course and for each MOOC module compared to those who were not active users (Hernandez et al., 2019). While alternative delivery methods to face-to-face courses prominently feature technology, not all reform efforts are categorized as CAI. Indeed, course-based redesigns are often used to address the length and timing of developmental mathematics courses.

Redesigned Course Approaches

Kosiewicz et al., (2018) explored alternative models used to deliver developmental mathematics courses found in the literature. From their study, the authors offered descriptions of acceleration, compression, and modularization as three common forms of delivery. They defined each, respectively, as a reduction in the number of courses, a reduction in course time while maintaining existing course sequences or contact hours, and smaller units of content tailored to a student's skill deficiencies. Corequisite courses are also described in the study as an approach to delivering developmental education and college-level curricula concurrently (Kosiewicz et al., 2018). Despite these general descriptions, however, specific instances of accelerated, compressed, corequisite, or modularized courses differ and, in some cases, interrelate as more than one approach is used.

Bishop et al. (2018) described a reduction of three semester-long courses totaling 48 weeks of instruction to eight accelerated modularized courses totaling only 32 weeks in North Carolina. Kallison's (2017) study reported an accelerated model with a 10-week-long course delivered to a cohort of adult learners at five sites in Texas, and Walker (2015) reported on an accelerated corequisite approach called the Accelerated Math Program combining a developmental mathematics course with a college algebra course. In the study conducted by Weisburst et al. (2017), courses were identified as accelerated if they were ten weeks or shorter in length. Also different among these studies were the variables of interest (e.g., pass rates, pre- and post-assessment achievement, and faculty perceptions) and outcomes. In two of the studies, statistically significant results were reported. Weisburst et al. (2017) found students in the accelerated model were more likely to pass developmental mathematics and the first college-level mathematics courses, and Kallison (2017) stated students’ achievement improved as determined by a pre- and post-assessment. Of note in Kallison’s (2017) study was despite the improved achievement, many of the students remained underprepared compared to state college readiness benchmarks.

Research published by Cafarella (2016), Hodara (2013), and Walker (2017) addressed the compressed delivery of developmental mathematics curricula, often incorporating elements of acceleration. Cafarella’s (2016) work explored compressed and accelerated courses in three community colleges. In one college’s initiative, five developmental mathematics courses were compressed into a single self-paced course, another college had three accelerated and self-paced courses, and a third institution compressed three courses into one. Hodara (2013) presented evidence from two institutions. At the New York institution, findings from campuses offering two and three courses were compared, and, in Denver, two semester-long courses were compressed into one, and student outcomes among those who took the compressed and traditional modes were compared (Hodara, 2013). The reduction of the developmental mathematics curricula to two nine-week courses featuring a compressed textbook on beginning and intermediate algebra as well as CAI for homework assignments was the focus of Walker’s (2017) study.

Other researchers looked at combining courses into a corequisite approach as opposed to reducing the number of weeks or courses in developmental mathematics curricula. Mireles et al. (2014) implemented the FOCUS model, which received funding as part of the Developmental Education Demonstrations Project in Texas, integrating developmental mathematics content into a college algebra course. The approach included incorporation of learning and academic support services and, unlike traditional developmental education courses, the corequisite college algebra course was credit-bearing (Mireles et al., 2014). Kashyap and Matthew (2017) compared a standalone developmental mathematics course to a corequisite course integrating the developmental-level content into a quantitative reasoning course.

Yet another type of approach is modularized, wherein developmental mathematics content is split into smaller segments. Ariovich and Walker (2014) described a modularized approach used in a community college at which three semester-long developmental mathematics courses were available. Fourteen self-paced modules were distributed across the three courses such that students could complete all modules in one semester, eliminating the need to take the final two courses or spread them out across two or three courses (Ariovich & Walker, 2014). Students were assessed using the ACCUPLACER placement test to determine which modules they needed to complete, and all instruction was computer-based with software used to deliver tutorials, homework, quizzes, and exams (Ariovich & Walker, 2014). The study by Bickerstaff et al. (2016) included discussion of modularized reforms in North Carolina and Virginia community colleges, and Edgecombe (2016) also detailed the modularized redesign in Virginia.

In both states, developmental mathematics content was distilled from one semester-long course into multiple one-credit modules; nine were created in Virginia and eight in North Carolina (Bickerstaff et al., 2016). The modules assigned to students were tailored to suit both students' skill levels and their majors. For instance, students pursuing degrees in liberal arts took fewer modules than did students majoring in science, technology, engineering, and mathematics (STEM) (Bickerstaff et al., 2016; Edgecombe, 2016). Students also chose in which course format they wanted to complete the modules. The first option was to take one module over four weeks at a time, while the second option was to enroll in a single course comprising all modules a student was required to complete, meaning the course length varied from four to 16 weeks (Edgecombe, 2016).

The four redesigns discussed have been used to address traditional course sequences in developmental mathematics. The specific details of how each is designed and implemented vary as do the outcomes of each study. While some researchers reported positive or statistically significant results, others indicated negative or mixed results, and some found no differences when compared to traditional methods. Kallison (2017) identified statistically significant improvements in achievement gains made by the adult learners who participated in the accelerated program; however, many of these students still did not reach college readiness benchmarks. Weisburst et al. (2017) also reported statistically significant findings. Students in the accelerated courses were 12% more likely to pass the developmental mathematics course and 2% more likely to pass their first college-level mathematics course within a year.

Mireles et al. (2014) found statistically significant increases in scores earned by students on a pre-post assessment, and the percentage of students who met state standards for college readiness more than doubled. The authors also found the students in the corequisite course earned a higher average course GPA when compared to those in the standalone college-level math course. Hodara (2013) found students who took the compressed course at one institution were more likely to enroll in and pass college-level mathematics after completing the compressed DM course; however, there were no statistically significant differences in their persistence rates or credits earned in college-level courses. At the other institution, those who took the upper-level compressed course, which was a blend of intermediate and higher-level algebra content, were more successful than those who took traditional developmental mathematics courses. Walker (2017) identified four benefits to the compressed CAI method, which included time reduction in students' enrollment in college-level mathematics, content not being repeated in the compressed course when compared to the traditional course, and student retention also exhibited improvement.

Kashyap and Matthew (2017) stated that students were more successful in the corequisite model, earning statistically significantly higher course grades than those in the developmental mathematics class. The students were also more positive in their feedback, noting they felt the developmental course felt like a setback, whereas students in the corequisite course appreciated having both levels of content with support from developmental and college-level mathematics faculty. Conversely, Bishop et al. (2018) reported no difference in success rates between the student groups who completed the traditional developmental mathematics course compared to those in the four-week accelerated format, and Ariovich and Walker (2014) reported mixed results. Students in the traditional, nonmodularized mathematics course performed better, passing the course at higher rates than the students who took the modularized courses, but those in the modularized courses were more likely to pass the next developmental mathematics course in the sequence than those who took traditional course. Edgecombe (2016) reported results from pilot-tested modularization in Virginia, noting more students who took the redesigned course enrolled in college-level mathematics within one year and earned higher grades in the college-level course compared to those who completed the traditional course format. Bickerstaff et al. (2016) reported concerns with the modularized approaches used in North Carolina and Virginia. Although some students failed the modules assigned to them, they frequently repeated and passed on the second try; however, multiple one-credit modules created more exit points than traditional course sequences and, while content was personalized to the students, their progress was often slow (Bickerstaff et al., 2016).

In the two qualitative studies on accelerated (Walker, 2015) and compressed (Cafarella, 2016) courses, faculty perceptions were positive. Faculty reported teaching accelerated courses was more rewarding than teaching traditional semester-long courses because their interactions with students were closer (Walker, 2015). As a result, the faculty felt they gained greater insight into their students' learning and noncognitive needs, and they reported learning more about various pedagogical strategies used in the accelerated course (Walker, 2015). Cafarella (2016) wrote faculty reported mixed feelings about how well the compressed initiatives took shape at their respective institutions.

Participants of one college, where the shift to compressed courses was led and managed by faculty, reported feeling more positive about the change compared to those reporting the redesign was instigated by administrators (Cafarella, 2016). The latter faculty participants indicated they felt frustrated by the inflexibility and lack of directive given by administrators who directed them to eliminate all face-to-face classes and figure out how to make it work because compression had worked elsewhere (Cafarella, 2016).

Though faculty reported accelerated instruction was a best practice for developmental mathematics students, they also cautioned the approach worked best for students with excellent time management and organization skills who are motivated (p. 55). Beyond redesigns for traditional developmental mathematics courses using accelerated, compressed, corequisite, and modularized approaches, some institutions and organizations have developed named models. Three examples gleaned from the literature will be discussed.

Model Examples

Several models used to reform developmental mathematics curricula were found in the literature. Model examples discussed in this portion of the review relate to emporium, pathways, and contextualized approaches. These three examples are not exhaustive; indeed, other models not discussed here include the Accelerated Learning Program used for developmental English reform (Jenkins et al., 2010), Structured Learning Assistance for corequisite courses (Austin Peay State University, 2017), Maryland Model focused on developmental education students' degree completion (Clagett, 2013), FastStart@CCD as an accelerated approach (Edgecombe et al., 2013), and more. The three examples offered here were the Emporium Model, Pathways—both Carnegie and Dana Center varieties—and I-BEST. Descriptions of each model structure and findings, where available, were presented.

The Emporium Model, or Math Emporium as it has also been called, originated 20 years ago as part of funded program initiative through the National Center for Academic Transformation (NCAT) to enhance instructional approaches with technology (Demiroz, 2016; NCAT, n.d.; Twigg, 2011). In the model, traditional instruction delivered via class meetings or lectures were eliminated and replaced by interactive computer laboratory environments. The labs functioned as learning resource centers where interactive software was employed to give students access to mathematics content and assign them homework, quizzes, and exams. Students received on-demand assistance, immediate feedback, and tutoring support as part of the interactive software and individuals staffed in the labs. During the NCAT initiative, four institutions—Northern Arizona University, University of Alabama, University of Idaho, and Virginia Tech—implemented the Emporium Model for differing levels of mathematics coursework (Demiroz, 2016; Twigg, 2011).

Twigg (2011) also described the model's replication and expansion to Louisiana State University for a college algebra course and, later, to two community colleges in Tennessee, where the approach was used for reforming the developmental mathematics curriculum. In the Tennessee approach, the three-course mathematics sequence was replaced by a modularized version of the emporium, in which students completed one module before proceeding to the next (Twigg, 2011). Kozakowski (2019) also reported on the use of emporium in the Kentucky Community and Technical College System. Across colleges in the system, three levels of developmental mathematics were offered, but a state law was passed in 2009, which required institutions to address students' college readiness (Kozakowski, 2019).

Of the 15 colleges in the system, the Emporium Model was implemented in pre- and basic algebra courses at ten institutions and in intermediate algebra courses at seven colleges (Kozakowski, 2019). Results reported by Twigg (2011) and Kowakowski (2019) were mixed. Twigg (2011) highlighted the cost reduction benefits of the model as well as positive outcomes in Tennessee, indicated by students' being twice as likely to receive a grade sufficient to proceed to the next mathematics course than before the model was implemented. Kozakowski (2019), however, found students who took a developmental mathematics course in the emporium format were 10% less likely to pass the course compared to 58% of students who passed the traditional course (p. 165). The disparity, Kozakowski (2019) explained, likely was due to the emporium model course enabling students to complete a course across multiple semesters; thus, a student may have earned an incomplete but reenrolled in the course a semester later. Still, the emporium students' who enrolled in the course for more than one semester were 9% less likely ever to pass it (Kozakowski, 2019).

Yet another model of reform for developmental mathematics is a pathway approach to guiding students toward college-level coursework. Merseth (2011) describes one of these approaches, Carnegie Math Pathways developed through the Carnegie Foundation for the Advancement of Teaching. The model has two pathways aimed at helping students gain mathematics skills in statistical reasoning (Statway) and quantitative (Quantway) literacy, which incorporate topics from developmental mathematics. Statway was created for non-STEM students and is intended to enable students to complete developmental mathematics and college-level courses in as little as one term in the Statway College and Statway Corequisite options or two terms in Statway Pathway (Carnegie Math Pathways, 2019b).

Similarly, Quantway can be delivered in one or two terms using corequisite and accelerated methods (Carnegie Math Pathways, 2019a). Merseth (2011) explained both pathways feature multiple lessons in module form for learners and provide a networking community among “practitioners, researchers, designers/developers, institutional leaders, students, and policymakers” with infrastructure for research and development (p. 37). Yamada et al. (2018) reported on students’ performance in the developmental mathematics class, Quantway 1, initially piloted in three states and later expanded to 10 colleges across eight states. Students who took Quantway 1 had statistically significantly higher odds of succeeding in the course and enrolling in college-level mathematics courses within a year compared to those students who did not participate in Quantway 1 (Yamada et al., 2018). The authors also studied the effects of the pathway learning environment for students of diverse backgrounds, noting the approach advanced equity for students from historically underserved groups (Yamada et al., 2018, p. 281).

A pathway approach was also a vital component of the Dana Center’s Mathematics Pathways (DCMP). The model was developed by members of the Dana Center at the University of Texas at Austin and the Texas Association of Community Colleges following a collaboration with members of the Carnegie Foundation (Charles A. Dana Center, 2019a). Incidentally, the collaboration resulted in the development of Statway and Quantway (Charles A. Dana Center, 2019a), and, like Carnegie Math Pathways, the DCMP includes pathways focused on statistics and quantitative reasoning (Altstadt et al., 2014). The first iteration of DCMP was the New Mathways Project, which later expanded beyond implementations in Texas and now features various projects involving math pathways (Charles A. Dana Center, 2019a).

The model is guided by four principles, which include having students enter the mathematics pathway aligned with their degree program and completing their first college-level mathematics course within the first year of college (Charles A. Dana

Center, 2019b). Altstadt et al. (2014) described the New Mathways Projects as having three routes involving a corequisite approach. Students enroll concurrently in a mathematical reasoning course and student success course, and, based upon their program of study, students also complete one of three mathematics courses. The three course options were a one-term course in statistical reasoning for those in social science and allied health programs, a quantitative reasoning course for those studying the liberal or fine arts, and an algebra-based course for students pursuing STEM majors (Altstadt et al., 2014).

The research brief written by Rutschow et al. (2017) focused on the newer DMCP, sharing findings from an evaluation of the model. The authors noted the findings indicated students who participated in the DMCP were more likely to enroll in and earn course credits for developmental mathematics compared to those students who were referred to the traditional mathematics course sequence (Rutschow et al., 2017). Evaluation findings were not limited to student performance, as indicated by Rutschow et al. (2017), who mentioned colleges implementing the DMCP also changed advising policies, ensuring students were placed in the correct mathematics pathway. Further, mathematics curricular alignment was successful in most instances between the pathways and requirements for many majors at four-year colleges with which the two-year institutions had partnerships (Rutschow et al., 2017).

There are many approaches to delivering developmental mathematics curricula to learners, ranging from traditional multi-course sequences; delivery modes using hybrid, online, and MOOC methods; efforts to accelerate, compress, modularize, and create corequisite courses; and employ new models guided by principles for using learning labs and pathways to facilitate students' completing developmental and college-level mathematics coursework. It must be stated many other reforms and redesigns are presented in the literature but are not discussed here. Examples of these included supplemental instruction (Potacco et al., 2008), learning communities (McHugh, 2011; Polczynski, 2016), summer bridge courses (Visher et al., 2017) and programs (Chingos et al., 2017; Dove, 2018; Harrington et al., 2016; Wathington et al., 2016), and the I-BEST model (Jenkins et al., 2009; Wachen et al., 2011).

This dissertation study was focused on technology as it has been used in developmental mathematics courses; however, nearly all the approaches not included were not course-based practices. The lone exception was I-BEST, in which basic skills and college-level and technical instruction were blended using accelerated, paired courses (Polczynski, 2014). The concern with including discussion of this model, however, related to I-BEST not being appropriately implemented for addressing developmental mathematics (Jenkins et al., 2009; Polczynski, 2014; Wachen et al., 2011). Of importance, most, if not all, of the practices discussed involve computer- or technology-mediated approaches to developmental mathematics (Kinney, 2001; Kinney & Robertson, 2003; Parcell, 2014). Now with a deeper understanding of technology use in education and various methods used in developmental mathematics teaching and learning, this literature review arrived at the intersection of both. The discussion then turned to research on technology-mediated developmental mathematics.

Technology-Mediated Developmental Mathematics

The phrase *technology-mediated developmental education* was used in this study because of its appearance in House Bill 2223 of the 85th Texas Legislature (Signed by Governor Abbott on June 10, 2017) and in the most recent statewide developmental education plan (THECB, 2018c). Its mention was part of the mandate for Texas institutions to use technology in developmental education programs. Discussion in this chapter has included literature about technology use in education and various modes, models, and practices employed in developmental mathematics. Examination shifted then toward presenting specific descriptions of, practices related to, and study findings from examples of technology-mediated developmental mathematics. Much of this discussion came full circle, referencing information previously presented about educational and instructional technology as well as reform and redesign efforts. Where possible, the literature addressing comparisons between technologies and practices or recommendations for selecting technologies was included.

Across the literature, technology-mediated developmental mathematics has been utilized for various instructional and pedagogical purposes. Technology has served an integral role in the redesign and reform efforts, such as in the emporium (Bonham & Boylan, 2011; Charters, 2014; Kohler, 2015; Kozakowski, 2019) and modularized approaches (Childers & Lu, 2017; Foshee et al., 2016). Technology has also been incorporated for assessment purposes (Edgecombe, 2016; Kadhi, 2005), as learning management systems (Natow et al., 2017), for online homework (Wladis et al., 2014; Spradlin & Ackerman, 2010), and as part of hybrid or online courses (Chekour, 2017). Still other literature was focused on descriptions of specific technologies, such as software (Chekour, 2014; Kashyap & Mathew, 2017; Kinney & Robertson, 2003; Prescott, 2017), an online platform (Chan et al., 2016), and calculators (MacDonald et al., 2002). Discussion of various practices, research, and technologies used begins with revisiting rationale for incorporating instructional technology.

Mastery learning was the focus area of Childers and Lu's (2017) research. At the authors' institution, a four-year university, a modularized and computer-based model was used. In attempts to redesign developmental mathematics curricula, a new initiative was created and titled the Pre-Core program. The program featured 10 content modules developed by statistics and mathematics faculty members, and students had to master one module before proceeding to the next. The learning environment also blended virtual and lab-based classrooms in which students met two times a week, receiving learning support from tutors. As other computer-based initiatives, software facilitated content delivery; in this case, ALEKS was the online program used to deliver mathematics instruction as well as homework and exams to students. As noted, mastery was required before a student could progress through the material. The ALEKS system was configured such that students had to earn a score of 80% or higher to move forward and, once the student completed eight modules, they could attempt an exit examination. If the student passed the exam, they could enroll in a quantitative reasoning or another college-level mathematics course; however, if they did not pass the exit exam or complete all 10 modules during the first semester, they could enroll in a second semester, Pre-Core II (Childers & Lu, 2017).

Foshee et al. (2016) also reported on a mastery learning approach using ALEKS to deliver mathematics education to underprepared students. Like to the approach described by Childers and Lu (2017), Foshee et al. (2016) explained ALEKS included video lectures, practice problems, feedback, and assessments. Students received individualized lessons based upon how they were performing, and instructors offered sessions to guide students through mathematical concepts; students were required to attend the instructor-led sessions (Foshee et al., 2016).

Consistent with mastery learning principles, students had to demonstrate mastery of each lesson before proceeding to the next one, and, as a self-paced approach, students could complete the lessons in as short as a few weeks or as long as two full semesters. Findings from both studies involving ALEKS for mastery learning indicated positive outcomes. Childers and Lu (2017) found more than one-third of students completed Pre-Core each semester and the average number of semesters required to complete the modules was 1.8. The authors also noted those who completed Pre-Core were statistically significantly more likely to have earned a higher mean score on the ACT Math, and close to 40% of these students later passed a college algebra course with another 18% passing the quantitative reasoning course (Childers & Lu, 2017). Foshee et al. (2016) reported students' performance on a pre-post assessment indicated statistically significant increases in their judgment of mathematics ability, reading skills, and critical thinking skills; however, students reported a decrease in study skills and motivation.

The Math Emporium is another approach discussed as technology-mediated developmental mathematics. A study conducted by Kozakowski (2019) involved using the emporium approach to teach up to three levels of developmental mathematics courses. As discussed previously, classroom instruction was replaced by computer labs at many Kentucky community and technical college campuses in multiple courses. A modularized and mastery-based model, the emporium enabled blended learning—a combination of online and in-person instruction—at the participating colleges, but with an unfortunate result. Indeed, Kozakowski (2019) reported students who participated in the emporium were markedly less likely to pass the developmental mathematics class compared to students enrolled in a traditional, face-to-face course. Even when accounting for students' completing the emporium modules across more than one semester, their pass rates remained lower.

On the other hand, Bonham and Boylan (2011) shared on benefits of the emporium model. For instance, a significant advantage to the model is it incorporates multiple teaching approaches wherein students learn how to do mathematics instead of listening to lectures. The authors also cautioned the "overreliance on the technology to deliver all instruction with little to no intervention" is a major disadvantage (Bonham & Boylan, 2011, p. 4). However, another publication about Math Emporium was from Kohler (2015), whose dissertation study was a comparison of students' performance in the technology-mediated approach versus the traditional lecture-based class. Like Kozakowski (2019), Kohler (2015) concluded students in the emporium completed the course at statistically significantly lower rates than their counterparts.

A study conducted by Charters (2013), however, reached a different conclusion. The integration of Math Emporium used software called MyMathLab through which students accessed instructional materials, homework, and quizzes. Rather than pass rates, however, Charters (2013) focused on the number of courses required by students who participated in the emporium model compared to those in a traditional face-to-face course. Charters (2013) concluded the students enrolled in Math Emporium required fewer courses to complete the developmental mathematics sequence compared to those in the traditional courses. The trend also held when students were divided into subgroups determined by age (i.e., traditional and nontraditional classification) and ethnic background.

In other accounts, the focus was on descriptions of how technology was used for assessing student learning and administering diagnostic tests. As discussed earlier, Edgecombe (2016) reported on redesign efforts in Virginia, which involved a modular approach to instructing developmental mathematics students. The modules were computer-based but also involved diagnostic testing, first, to determine the modules students should complete, then to evaluate students' mastery of content and skills. Diagnostic tests were launched at different points in the modules. For instance, one diagnostic test was administered after students completed the modules related to introductory algebra and another was once students mastered intermediate algebra content and skills. The incorporation of technology for diagnostic testing proved critical, especially for students with STEM majors, because the tests were also prerequisites for more advanced college-level courses; specifically, STEM students were required to master both module levels and pass the diagnostic tests to qualify for a precalculus class in advance of a required calculus course (Edgecombe, 2016).

Kadhi (2005) also studied technology integration related to diagnostic testing; however, the focus was on how to develop effective computer-based assessments for developmental mathematics courses. Engaging in research and development, Kadhi (2005) relayed the development of Fraction Diagnoser as a tool for assessing various facets of thought and reasoning strategies used by students. After creating Fraction

Diagnoser, Kahdhi (2005) studied its reliability and validity in assessing learning among developmental mathematics students and elicited feedback from faculty regarding the capability of online assessment via this or other tools. Faculty's comments suggested positive perceptions of online assessments such as Fraction Diagnoser.

Technology-mediated developmental mathematics is also portrayed in hybrid and online delivery modes, supplemental capabilities for online instruction or homework, specific platforms or software, and as a course management system. Chekour (2017) published a literature review comparing past studies of hybrid and online developmental mathematics. The focus of the review was on whether hybrid or online delivery modes had resulted in better outcomes for students. Chekour (2017) highlighted the balance and benefits of hybrid approaches, explaining the hybrid format maintains face-to-face interactions between teachers and learners as well as learners with their peers. Yet, Chekour (2017) did not discount the benefits of online learning; indeed, the author explained online methods enable supplementation of classroom instruction through assignments and tutorials integrating text and media. Supplemental resources were a key component in online delivery, and opportunities for individualized and regulated instruction were possible (Chekour, 2017). The author also pointed out online instruction has the benefits of immediate feedback; however, Chekour (2017) stated online delivery lacks balance inherent to hybrid delivery but suggested additional research was needed to study further the benefits and limitations of both approaches.

Related to online course delivery is online homework, which was discussed by Wladis et al. (2014) and Spradlin and Ackerman (2010). In both examples, online homework supplemented traditional face-to-face courses; however, the study procedures differed. Wladis et al. (2014) presented use of online homework to address deficiencies determined by midterm examinations taken by students in a developmental mathematics course. The students required to complete the homework were those earning lower than 70% on the midterm examination, while students scoring higher received no supplemental assignments. The homework assignments were self-paced online modules, and students completed only those they required based upon their exam performance. Wladis et al. (2014) noted some students were resistant because their peers who scored higher on the midterm exams were not assigned additional homework. For the students who completed the homework, their pass rates statistically significantly improved, especially among those who spent 20 hours or more using the online system.

The study conducted by Spradlin and Ackerman (2010) compared developmental mathematics students who took a traditional face-to-face course in which all homework and assessments were on paper and another group of students who attended the same course format but received supplemental homework online. The homework assignments ranged from 10 to 15 questions each and included ungraded practice problems, which enabled immediate feedback to the students after submitting their work. Feedback was also available to instructors who could review the time spent by students in the online system, number of attempts for each assignment, specific answers given to each question, and their grades. When comparison was made, Spradlin and Ackerman (2010) concluded those enrolled in the technology-enhanced course earned higher grades than those without online support; however, the difference was not statistically significant.

Other technology-mediated developmental mathematics approaches involved computer-based software, including platforms like Connect Math, Khan Academy, and

MyMathLab, which allow students to receive instructional materials and complete practice problems, assignments, quizzes, and exams. Prescott (2017) discussed the use of Connect Math in a developmental mathematics course. A traditional lecture-based course was modified to incorporate Connect Math for completing homework and quizzes but did not completely replace face-to-face delivery. The other differences were students in the technology-mediated course met less frequently and, when they did, they met in a computer lab, whereas those in the non-computer-mediated course met more frequently in a traditional classroom. Student performance as determined by course GPA was compared between the groups. Prescott (2017) found the students who participated in the course supplemented with Connect Math earned slightly higher GPAs than those in the traditional course; however, the finding was not determined to be statistically significant.

Yet another software approach to developmental mathematics was reported by Chan et al. (2016). In their study, Khan Academy was used to support a traditional lecture-based course across multiple colleges. Chan et al. (2016) noted the specific implementations of Khan Academy varied, however, in that the platform was part of blended learning classrooms at some colleges, while it was used for self-paced, modular, or supplementary to traditional approaches. Chan et al. (2016) provided a brief background of Khan Academy, noting it is a nonprofit educational organization with an online learning platform used to facilitate personalized learning for students through content videos, practice exercises, and mastery challenges. The authors analyzed grade data collected from the colleges and found statistically significant positive correlations between the use of Khan Academy and students’ final course grades. They also determined that the more mastery exercises students completed, the higher the grades they earned (Chan et al., 2016).

Two additional studies focused on the software platform MyMathLab. The program, developed by Pearson, was used in studies reported by Chekour (2014) and Kashyap and Mathew (2017). In the first study, MyMathLab was used as a supplement for a developmental mathematics course taught in a traditional, lecture-based format. For comparison, a traditional course without MyMathLab supplementation was also included. Using a pre-post assessment approach, Chekour (2014) found students in the MyMathLab course version performed statistically significantly better on the post-assessment than students enrolled in the other course.

Similarly, Kashyap and Mathew (2017) explored the use of MyMathLab in a corequisite course in which developmental and college-level mathematics were combined. Students in the corequisite course completed homework assignments and practice problems in MyMathLab, and their performance was compared to students in a traditional developmental mathematics course incorporating neither corequisite redesign nor MyMathLab. Like Chekour (2014), Kashyap and Mathew (2017) found students earned statistically significantly higher course grades in the MyMathLab enhanced corequisite course compared to the traditional, non-corequisite course. While discussion of technology-mediated developmental mathematics has focused primarily on computer-aided or -based uses, calculators are also featured in the literature.

One example was found in a paper by MacDonald et al. (2002) who discussed calculators as an effective form of technology. The authors described three cases of calculator use in developmental mathematics courses. At one college, graphing calculators were used to help students learn about “tables, graphs, and symbolic representation,” and were covered in instruction (MacDonald et al., 2002, p. 36). In the second example, real-world problems requiring mathematics skills to find solutions resulted in the use of graphing calculators to aid in data collection and, in the third case, graphing calculators to facilitate students’ mastering mathematical modeling skills and critical thinking. Related to calculators, MacDonald et al. (2002) also described the use of spreadsheets via Microsoft Excel in a developmental mathematics classroom in which students were able to see quantitative input translated into visual graphs and learned about functions via Excel’s built-in formula feature.

Although not an account of technology implementation, Natow et al. (2017) reported on a wide range of tools integrated for instructional, course management, and student support purposes. Their study involved semi-structured interviews with instructors, institutional leaders, and other key stakeholders based in 42 two- and four-year public colleges and more than 40 organizations charged with overseeing the colleges. The authors presented a detailed list of technology used in developmental mathematics, which included instructional technology, course management systems, and student support technologies. Natow et al. (2017) shared instructional technology included software, such as the previously discussed ALEKS, Khan Academy and MyMathLab, as well as open educational resources and video content.

Course management systems identified by the authors included Blackboard, Canvas, Moodle, and others, which were described as storage systems used particularly for online courses and enabled students to communicate within a virtual class. Finally, student support technologies identified were defined as those providing developmental education students with extracurricular assistance, including advising, tutoring, and early alerts. Perhaps most valuable in this reporting were challenges identified by interview participants. Challenges encountered by stakeholders included a lack of sufficient skills to use the technology or participate meaningfully in an online course, the reduction of in-person interactions, cost issues for institutions and students to acquire the technology, limited resources for labs and faculty training, and technical issues in which the technology was not available due to equipment inappropriate for access and Internet outages (Natow et al., 2017).

Also relevant to these studies of technology-mediated developmental mathematics, Kinney and Robertson (2003) voiced concerns about the limitations of the software. The authors argued instructional materials included in such software are intended to support, not replace, instruction; however, Kinney and Robertson (2003) shared there are benefits to integrating software, including the variety of media and text learning tools included as well as the organization and presentation of mathematical concepts. Kinney and Robertson (2003) explained learner-centered, technology-mediated instruction might replace traditional instructional formats so long as diverse resources and media are incorporated, and the software is used for assessment and feedback to both students and teachers. Another contribution from the authors was their suggestions for how software and instructional technology should be selected. For instance, one must decide in advance what the roles of the instructor and software will be, how the materials will be presented, what types of practice and feedback are suited for the students, what multimedia to use in presentations of concepts and skills, and whether content will be individualized, self-paced, or organized in pathways.

Conclusion

This chapter explored the literature relevant to the study topic through three overarching themes. The first theme was aimed at providing background and context to the landscape of technology use in education, including definitions of educational and instructional technology and other phrases like learning technology and e-learning. In the second theme, several practices used in developmental mathematics instruction were presented. These practices included alternative delivery modes, efforts in redesigning traditional courses, and models used to reform developmental mathematics initiatives. In the final theme, technology-mediated developmental mathematics descriptions and studies were presented. The range of technologies used included software like ALEKS, Connect Math, Khan Academy, and MyMathLab; were part of the emporium model, mastery learning approaches, and modularized courses; were implemented to administer diagnostic tests; were essential to hybrid and online delivery modes; involved online homework for supplementing traditional lecture-based instruction; and included graphing calculators.

Before proceeding to the following chapter, however, a notable gap in the literature required mention. Studies and reports were discussed in attempts to share descriptions of technology use in developmental mathematics settings; indeed, such works were plentiful across the extant literature. Conversely, few pieces involved exploring state policies related to developmental education or developmental mathematics, especially concerning technology use. Moreover, the current body of literature had not yet arrived at standards or best practices for effective design, implementation, and assessment of technology-mediated developmental mathematics.

This issue proved challenging in Texas, where this dissertation study is set, because state policy has been created with a mandate for developmental education to be technology-mediated and for such practices to be research-based. It was, thus, a hope this study would contribute to addressing this literature gap through research methods intended to explore whether technology use in developmental mathematics and student performance were related.

CHAPTER III

Method

The purpose of this study was to explore whether technology use relates to student performance in developmental and college-level mathematics courses. Technology use was identified using publicly available course syllabi. Student performance referred to whether students earned credit for the developmental mathematics course given that grading for developmental mathematics courses is determined on a credit and non-credit basis. Conversely, college-level mathematics courses involved letter grades on a five-point scale ranging from A to F. Using the I-E-O model as a conceptual framework, technology use served as the environmental variable and student performance will be the outcomes variable. The inputs variable was used only for descriptive purposes and will be students' prior mathematics knowledge, as determined by the TSIA.

To inform this study and provide a framework for interpreting the research findings, Astin's I-E-O model (1991) was used as a conceptual framework. The model included three components—inputs, environment, and outcomes—that provide flexibility and adaptability (Judd & Keith, 2012). Although the model's original form used students' characteristics as inputs, the variable is flexible and can be adjusted to meet varying research needs (Astin, 1991; Judd & Keith, 2012). In this study, the inputs referred to students' prior mathematics knowledge, which were a descriptive variable; the environment variable was technology use in developmental mathematics courses; and the outcome variable was defined as student performance. The rest of this chapter outlined specific details about the research methods for conducting this study.

Research Questions

As introduced in the first chapter, there were two research questions that guided this study.

1. How does student performance in developmental mathematics courses relate to the integration of technology in developmental mathematics courses?
2. How does student performance in gatekeeper mathematics courses relate to technology use in developmental mathematics courses?

Null Hypothesis

The first null hypothesis related to the first research question. This hypothesis was there was no statistically significant relationship between student performance (earning credit) and technology use in the developmental mathematics courses. For the second research question, the null hypothesis was there was no statistically significant relationship between student performance (grade earned in the college-level mathematics courses) and technology use in the developmental mathematics courses for which the student earned credit. The alternative hypothesis for each question was there was a statistically significant relationship between technology use in the developmental mathematics courses and student performance in either the developmental or college-level mathematics courses.

Research Design

In order to address sufficiently the research questions, a quantitative design was considered best fitting. Notably, the research questions required computing figures related to descriptive statistics, such as means and standard deviations, and calculating the chi-square statistic and *p*-values. For these reasons, only a quantitative research approach could be taken. This study used a descriptive, nonexperimental design, indicating participants were not separated into control and treatment groups, and there was no random assignment of participants to groups. Archival data for student performance was acquired, with permission, through the Office of Planning and Assessment at the College of Education, and archival data via course syllabi were collected through the institution's website by the researcher to ascertain technology use in developmental mathematics courses.

Study Setting

The setting for this dissertation study was a four-year public university located in Texas. As per state policies used to govern developmental education programs, the institution is subject to the technology-mediated requirement presented in the introductory chapter and enacted in 2011. At the time of the study, the university had enrollment of more than 21,000 students with a large percentage of students who lived off-campus and commuted to classes. At the university, developmental mathematics instruction was delivered using a corequisite approach, also consistent with Texas requirements for shifting developmental education courses towards this redesign. Students must pass the course to proceed to college-level mathematics coursework. Specific course numbers for the gatekeeper college mathematics course varied based upon the student's degree program. For instance, students pursuing degrees through the business school took a course related to mathematics for business decision-making, whereas students pursuing STEM majors completed college algebra and precalculus before enrolling in any upper-level mathematics courses required by the program.

Participants

Study participants were previous developmental education students who placed into developmental mathematics coursework based on their performance on the TSIA. Students who took the TSIA and did not meet state-established score benchmarks are referred to developmental education coursework in the relevant subjects. Students included in the study attended at least one developmental mathematics course between the Summer 2011 through Fall 2019. The students may have begun their college careers at a local community college and transferred to the institution having taken or completed developmental mathematics coursework; however, participants may have been those who attended courses only at the university where this study is conducted.

Data Source

There were three categories of data sourced for this study. The first data category came from archival institutional data provided by the Office of Planning and Assessment in the College of Education. This source was Ellucian Banner, a database containing data on students, including demographics, course enrollment history, and grades. Data were targeted to students who attempted developmental mathematics coursework and, subsequently, a college-level mathematics course between Summer 2011 and Fall 2019. The second data category related to the input variable identified for this study, students' prior mathematics knowledge. The source for this data was also Ellucian Banner, which was accessed by an institutional assessment analyst with the Office of Planning and Assessment to collect archival data containing the scores earned by students on the TSIA. Because the TSIA was implemented in Fall 2013 as the official instrument for assessing students' college readiness in Texas, these data were not be accessible for students who first enrolled in the university between Fall 2011 and Summer 2013. The final data category referred to information regarding technology used in developmental mathematics courses. This data source was publicly available due to House Bill 2504 (Signed by Governor Perry on June 19, 2009), which went into effect in Fall 2010 and mandated all Texas higher education institutions to post a course syllabus for each course, a curriculum vitae for each instructor, and a recent budget report for each academic department. The course syllabi were also archival data and were downloaded from the appropriate institutional website.

Procedure

Following approval by the committee overseeing this dissertation, permission to conduct this study was requested from the university's Institutional Review Board (IRB). Archival data was used and the researcher did not have contact with human subjects; however, there were ethical considerations. Two of the data sources described previously contained names and other sensitive information about students. The institutional assessment analyst with the Office of Planning and Assessment implemented an algorithm to mask the identity of each participant; thus, all names were replaced by a five- to seven-digit alphanumeric code depending upon the number of participants listed in the data sources. The original intent was to capture data for students who attempted developmental or college-level mathematics courses more than once, and retaining the alphanumeric code so the researcher could compute the average number of attempts students made before passing either course. Unfortunately, grades and credit status were only available for students' final course attempt, eliminating the ability to calculate their average attempts for a course as well as the need to match the alphanumeric code for this purpose. This approach did not risk breaching participant anonymity as the alphanumeric code was not decipherable without an encryption key and did not represent any known sequence of letters and numbers relevant to the research methods or this dissertation study.

Once data from all three sources were acquired, they were transferred into SPSS for data processing. Course information from the student-level data were matched to data obtained through the course syllabi and appended to each line of data accordingly. Some data variables were recoded, like setting a zero to represent a student earned no course credit and a one to represent course credit was earned for the developmental mathematics course. Similarly, course grades for the college-level mathematics were coded from one to five in accordance with the institution's five-point grading scale. Finally, technology identified in course syllabi were coded in two ways. First, technology use was a nominal variable in that a zero meant technology was not used and a one meant technology was integrated in the course. Second, types of technology were captured and coded accordingly in SPSS, such as a one representing a scientific calculator, a two representing a graphing calculator, three indicating software was used, and so on. After data were prepared for processing, data analysis ensued.

Data Analysis

Data collected for this study were analyzed using descriptive statistics, frequencies, and chi-square tests of association. Descriptive statistics were computed for the mean course GPA earned by students enrolled in college-level mathematics courses as well as the standard deviation. Similarly, the mean and standard deviation were to be determined for the number of attempts required for a student to pass a developmental or college-level mathematics course. Because the number of course attempts for the students were not available through the data sources used, only the mean and standard deviation of total developmental mathematics and gatekeeper mathematics courses were computed. Descriptive statistics were also calculated for TSIA scores representing students' prior mathematics knowledge. Because student performance variables for the developmental mathematics courses were categorical, frequencies were calculated to explore the percentage of students who earned credit for the developmental mathematics course.

To more directly answer the two research questions in this study, a chi-square test of association was conducted for each. The chi-square approach was recommended when analysis focuses on determining the relationship between two nominal or categorical variables. The chi-square was considered nonparametric and there are assumptions of this statistical test the researcher had to verify. The assumptions were that data were drawn from random samples, the variable categories (i.e., technology use as environments and student performance as outcomes) were independent of each other, and the expected value of each cell in the contingency table was greater than or equal to five (Davis & Davis, 2015). For most analyses, the chi-square test assumptions were not violated; however, some instances required an alternative statistic be used because the expected values were smaller than five, thus, the Fisher's exact test was computed. Situations in which Fisher's exact test was used are noted in Chapter 4.

For the first question, the primary variables of interest were whether technology was used in the course, stated as yes or no, and whether the student earned credit for the developmental mathematics course, again a yes or no categorical variable. For the second question, the variables of interest were yes or no that technology was used in the developmental mathematics course and the letter grade earned in the college-level mathematics course. A two-by-two contingency table was developed to examine the relationship between technology use and student performance for the first question and a five-by-two contingency table was developed for the second question. As stated previously, the null hypothesis for both questions was that there is no relationship between technology use and student performance and the alternative hypotheses is there was a relationship between the two variables. The chi-square statistic (χ^2) was computed using SPSS. Where data analysis results indicated an association between the two variables, the finding was reviewed for statistical significance using $p < .05$. As needed, effect sizes were reported for the statistically significant associations. Phi (ϕ) was the appropriate effect size measure for the two-by-two contingency table used to analyze data for the first research question and Cramer's V (V) was the appropriate effect size measure for the five-by-two contingency table relevant to the second research question (H. Kim, 2017).

Summary

A descriptive, nonexperimental quantitative research design was used to explore relationships between technology use in developmental mathematics courses and student performance in both developmental and college-level mathematics classes. The null hypothesis for the two research questions in the study was that there is no relationship between the variables. Participants were identified as students of a four-year public university in Texas who enrolled in a developmental mathematics course between Summer 2011 and Fall 2019. To explore the variables in this study, three data sources were used, each containing archival data. Data from two of the sources were acquired from the Office of Planning and Assessment at the College of Education, and data from the third source was collected using a publicly available database hosted via the university’s website.

Ethical concerns related to the researcher’s obtaining educational records data were also addressed. Because data from the first two sources contained participants’ names and other sensitive information, the institutional assessment analyst deployed an algorithm to mask the identities of all participants, ensuring deidentified data were provided to the researcher. After appropriately translating the data into a single SPSS database, descriptive statistics and frequencies, where appropriate, were computed. To evaluate the relationship between technology use and student performance, the chi-square test of association was performed to analyze the data. Following a review of the data and, based upon the results of data analyses, the next chapter presents the findings and tables, where appropriate. The final chapter then focuses on discussing the findings and considering the implications for future research and practice in technology-mediated developmental mathematics.

CHAPTER IV

Results

The findings of this study are presented in this chapter. These results are comprised of descriptions of student participants and information about the developmental and gatekeeper mathematics courses involved and that facilitated answers to the two research questions. Prior to acquiring and analyzing the data collected for this study, approval was sought by the Institutional Review Board (IRB). The study was identified as exempt.

Data Description and Collection Process

Following IRB approval, the data collection process began with a request sent to the assessment analyst with the Office of Planning and Assessment. This portion of the data focused on student performance details for those who enrolled in at least one developmental mathematics courses, including grades earned in developmental and entry-level, or gatekeeper, college mathematics courses, as well as scores earned on the Texas Success Initiative Assessment (TSIA). The researcher of this study downloaded developmental mathematics course syllabi as PDFs using the public database hosted on the university’s website. The specific developmental mathematics courses of interest were identified using the university’s undergraduate catalog. The core curriculum list also found in the catalog was used to determine the appropriate gatekeeper mathematics courses to include. Archival data of students’ TSIA scores, and developmental and gatekeeper mathematics course grades were combined into a single, password-protected Excel file. The file contained 10,391 rows of data, each corresponding to a student who enrolled in at least one developmental mathematics course at the university. Student names were removed from the data and their student identification numbers were deidentified using a masked number.

There were 63 course syllabi downloaded and examined for evidence of technology used in the developmental mathematics courses. Syllabi were departmental, meaning only class schedules and instructors varied while other course attributes and policies remained consistent for a particular class during each semester. Thus, only one version of the syllabus for each developmental mathematics course per semester was necessary to identify the technologies used.

Timeframe Adjustment

The file containing archival data was reviewed to confirm the appropriate information was requested. Previously, Summer 2011 and Fall 2019 were identified as the time bounds for this study. Upon review of the effective dates of the *2012-2017 Statewide Developmental Education Plan*, amendments to relevant sections of the Texas Administrative Code and Texas Education Code, and governor's signings of various House Bills passed by the Texas Legislature related to developmental education, the timeframe was adjusted to Fall 2011 and Fall 2019. As such, several data rows were removed from the file because they referred to students enrolled in a developmental mathematics course prior to Fall 2011 or in Spring 2020. The final number of participants in this study was 9,283.

Developmental Mathematics Student Characteristics

The analytic sample (n = 9,283) was predominately female (63.1%, n = 5,855) and less than two-fifths male (36.9%, n = 3,424), with four students who did not report their gender. Regarding students' ethnicity, 40.5% (n = 3,756) were identified as White, 31.8% (*n* = 2,954) were African American, 20.9% (*n* = 1,940) were Hispanic, and 5.8% (*n* = 537) were of American Indian, Asian, Native Hawaiian, International, and Multiethnic backgrounds. Only 1.0% (*n* = 96) of students did not have an ethnicity reported in the data. The data were also examined for the number of first-time-in-college (FTIC) students. Although most participants 43.2% (*n* = 4,013) were of unknown FTIC status, the remainder were nearly evenly split with 27.2% (*n* = 2,526) who were and 29.6% (*n* = 2,744) who were not FTIC students. The university is known for having a large percentage of students who live off-campus and commute to classes. There are also several degrees that may be attained through online programs, which would not require a student to live near campus to attend classes. Although students hailed from across the contiguous United States, the vast majority (98.7%, *n* = 9,103) reported residing in Southeast Texas. This included nearly 1,000 students who reported living in the campus vicinity. A zip code map was generated to visualize the dispersion of students living in Texas wherein darker shading represented greater population density. This map appears in Appendix A.

Frequencies also were computed to explore students' academic characteristics. Specifically, students' majors, graduation status, last reported grade point averages (GPA), and more were reviewed. Across the participants, 32% (*n* = 2,973) graduated, while 68% (*n* = 6,310) did not. This percentage was smaller compared to the 36.9% of students who graduated from this university within four years as well as the 58.8% who graduated within five years and 64.7% within six years (THECB, 2018b). Among those who graduated, the top 10 majors and the eight undergraduate degrees awarded appear in Table 1 and Table 2, respectively.

Table 1

Top 10 Majors Recorded for Graduates Who Took Developmental Mathematics Courses

Majors	Total Graduates	
	N	%
Criminal Justice	657	22.1
Interdisciplinary studies	227	7.6
Mass communication	178	6.0
Psychology	173	5.8
General business	169	5.7
Kinesiology	151	5.1
History	76	2.6
Victim studies	75	2.5
Public health	74	2.5
Animal science	63	2.1

Table 2

Undergraduate Degrees Earned by Graduates Who Took Developmental Mathematics Courses

Degree	Total Graduates	
	N	%
Bachelor of Arts	576	19.4
Bachelor of Applied Arts and Sciences	385	13.0
Bachelor of Business Administration	174	5.9
Bachelor of Fine Arts	60	2.0
Bachelor of General Studies	427	14.4
Bachelor of Music	591	19.9
Bachelor of Science	699	23.5
Bachelor of Science in Nursing	61	2.1

Developmental mathematics students graduated from programs with a similar percentage across four of the seven colleges. Students who majored in areas in the arts and media accounted for 12.0% of graduates, and nearly 15.0% of graduates each studied in the health sciences, humanities and social sciences, or business administration. The exceptions were those who majored in criminal justice, accounting for nearly one-quarter of graduates, and students who majored in education or science and engineering technology programs, both of which had fewer than 10% of graduates among those who enrolled in at least one developmental mathematics courses. A more detailed breakdown of the percentage of students who graduated from each of the university colleges is shown in a pie chart in Appendix B with an accompanying table of the percentages and counts in Appendix C. About one-third of students who majored in programs at each of the seven colleges graduated, which was consistent with the 32% of total graduates. Thus, students in all program areas were approximately equally likely to graduate, although most students overall and by college did not graduate.

It is important to note that, among the 68% of students who had not graduated, there was a subset who would not have had the chance to complete their degrees by the Fall 2019 cut-off used for the study. Based upon enrollment dates for developmental mathematics courses, these students would have been enrolled for less than four to six years. In accordance with university policy, students likely enrolled in developmental mathematics courses during their first year because such courses are prerequisites for gatekeeper mathematics courses (SHSU, 2018a). Further, the time to earn a degree at the university ranged between four and six years as reported by the institution (SHSU, 2018b) and the Texas Higher Education Accountability System (THECB, 2021), both of which indicated at least half of students graduated within this timeframe. More specifically, 33% of undergraduate students at the university who were part of the 2013 entering cohort graduated within four years, and 52% of those who entered as part of the 2011 entering cohort graduated within six years (SHSU, 2018b). Thus, those who attended a developmental mathematics course between Fall 2015 and Fall 2019 were members of this subset of participants. The total number of students in this subset accounted for 53.8% (n = 3,395) of the nongraduates. Thus, the graduation status of students included in this study may be best characterized as 32% (n = 2,973) graduated, 31.4% (n = 2,915) did not graduate, and 36.6% (n = 3,395) did not graduate but had not yet reached the estimated timeframe to graduate of between four and six years until the 2020-2021 academic year and beyond.

Beyond degree-related characteristics, the GPA for each student also was reviewed. The mean GPA earned by all developmental mathematics students included in this study was 2.35 (SD = 0.95), using a traditional four-point scale. Among those who completed a degree at the university, they earned a mean GPA of 2.97 (SD = 0.45), whereas those who did not graduate—those students who were part of entering cohorts in 2011 to 2014—earned a 1.90 (SD = 0.88), and those who had not yet had a chance to graduate—those who were members of the entering cohorts between 2015 and 2019—earned a mean GPA of 2.21 (SD = 1.04). The difference between the mean GPA of these three groups was statistically significant, as determined by a one-way analysis of variance (ANOVA), $F(1, 9278) = 1264.38$, $p < .001$, and with a large effect size ($\eta^2 = .21$). When comparing each group, students who did not graduate earned statistically significantly lower GPAs compared to those who had not reached the average time to graduation ($p < .001$) and those who did graduate ($p < .001$). Graduates earned a mean GPA that was statistically significantly higher than both nongraduates ($p < .001$) and those who had not yet reached time to graduation ($p < .001$). Finally, students in the subset of participants who had not yet had a chance to reach graduation earned a mean GPA that was statistically significantly higher than those who did not graduate ($p < .001$) and statistically significantly lower than those who did graduate ($p < .001$).

Prior Mathematics Knowledge

In reference to the I-E-O model used as the conceptual framework for the study, the inputs component was defined as students' prior mathematics knowledge. The scores earned by students on the TSIA were considered descriptive of the students' prior mathematics knowledge. The TSIA became the state-mandated placement test for determining whether incoming higher education students were college-ready, including in mathematics, beginning in Fall 2013. About one-third of students had a TSIA score available in the data set.

Of the 3,868 developmental mathematics students who took the TSIA, their scores ranged from 260 to 372 with a mean of 339.79 (*SD* = 9.06). For perspective, the college readiness benchmark for mathematics was a score ranging from 350 to 390, with those scoring below 350 likely to be referred to developmental mathematics coursework. These scores were explained in the TSIA handbook (College Board, 2018) and consistent with Texas Administrative Code (19 Tex. Admin. Code, § 4.57, 2013) initially revised in 2013 with these benchmarks. Of note, the TSIA has since been replaced with the TSI Assessment Version 2 (TSIA2) as of January 2021 (19 Tex. Admin Code, § 4.56, 2020). Students now must achieve a score of 950 or higher to be eligible for college-level mathematics coursework (College Board, 2020; 19 Tex. Admin. Code, § 4.57, 2020).

Developmental and Gatekeeper Mathematics Courses

As explained, a list of developmental and gatekeeper mathematics courses was obtained using the university's undergraduate catalog. This approach resulted in the selection of eight developmental mathematics courses and 10 mathematics courses that satisfy the state's core requirement for mathematics with each identified as an entry-level, or gatekeeper, course. Numerically, the first two developmental mathematics courses were MATH 0112 and MATH 0212. Both courses were titled "Intermediate Algebra," but the 0112 version was described as an accelerated course while 0212 is of traditional course design (Sam Houston State University [SHSU], 2020b). MATH 0331 was titled "Developmental Mathematics" and included topics from introductory algebra and geometry. MATH 0332 was "Intermediate Algebra," but also known as "Developmental Mathematics II" (SHSU, 2013). These two courses were traditional approaches to developmental mathematics, in that they each were a semester in length and, combined, comprised two levels of developmental mathematics that could be taken sequentially if a student required more than one level of developmental mathematics instruction. MATH 0333 was the non-course-based option (NCBO) of "Developmental Mathematics" offered as a one-term, accelerated course.

Finally, MATH N014, N024, and N032 were "Intermediate Algebra" classes that were NCBO and accelerated, corequisite courses wherein each was tied to a specific gatekeeper mathematics course. As indicated, many of these developmental mathematics courses covered similar content and, in some cases, had the same title. The developmental mathematics course taken by the student participants varied primarily by the academic year in which they were taken because of changes to Texas policies for developmental education, such as the requirement of accelerated and corequisite courses beginning Fall 2017 (THECB, 2018b; 3 Tex. Edu. Code § 51.331, 2017). The years during which each developmental mathematics course was offered and the number of students who were enrolled in these are displayed in Table 3.

Table 3

Student Enrollment per Developmental Mathematics Course by Academic Year

Course Code	Academic Year								
	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
0112				63	156	88			
0212				12	64	28			
0331	285	325	243	119	137	96			
0332	1,605	1,621	1,657	306	531	794			
0333							603	339	374
N014							66	169	140
N024							36	80	83
N032							60	187	124

Note. Only enrollment counts for Fall 2019 were available for the 2019-2020 academic year.

Ten entry-level college mathematics courses were included in this study. MATH 1314 was “PreCalculus Algebra,” MATH 1316 was titled “Plane Trigonometry,” and

MATH 1324 was “Math for Managerial Decision Making,” a course required of all business and a few other selected majors. MATH 1332 was “College Mathematics,” both MATH 1369 and STAT 1369 referred to “Elementary Statistics,” and MATH 1384 was “Introductory Foundations of Mathematics I,” which was required of students with education majors seeking elementary or middle school certification. MATH 1410 was “Elementary Functions,” which is a gatekeeper mathematics course as well as a prerequisite for MATH 1420, “Calculus I.” Finally, PHIL 2352 was “Introduction to Contemporary Logic,” a course launched in Fall 2014 for students with developmental learning disabilities (SHSU, 2020a). Three of the above gatekeeper mathematics courses were also made available as corequisite courses linked with a developmental mathematics course. Specifically, MATH N014 was linked with MATH 1314, N024 with 1324, and N032 with 1332. Of note, the gatekeeper course taken by a student could vary based upon the requirements of their major.

Technology Used in Developmental Mathematics Courses

Explained earlier in this chapter was the process for obtaining technology data for the student participants based upon the content of developmental mathematics course syllabi. A list of commonly used technology in developmental mathematics was compiled from various literature discussed in Chapter 2. The resulting list was graphing calculators, scientific calculators, learning management systems, online homework, course software, online supplements, and e-textbooks. These seven technologies also were selected because of their use for teaching and learning, such as for homework, exams, and class sessions. The learning management system referenced in all applicable course syllabi was Blackboard. Additionally, online supplements referred to external resources used for teaching and learning. These were described as web modules, websites, and podcasts about specific topics covered in the course. Related to the I-E-O model, technology was identified as the environment component.

To answer appropriately the research questions guiding this dissertation, technologies were appended to the data alongside a binary variable used to generally describe whether a student encountered a developmental mathematics course in which the specific technology was used. A zero indicated none of the technologies were used, while a one indicated at least one form of technology was reported in the syllabus. One example of technology found in syllabi but not considered for this study was online tutoring. All syllabi included mention of tutoring services; however, online options were shared in some instances. For example, during Spring 2012, MATH 0331 and 0332 included online tutoring via MyLabsPlus (MPL), the software required for homework assignments. Also, from Spring 2018 through Fall 2019, the corequisite developmental mathematics courses (N014, N024, N032) referenced the Ada Lovelace Online Tutoring (ALOT) program offered through the university (SHSU, 2019). Because tutoring was external to the classroom environment, meaning there was no way to verify whether and which students used online tutoring services, this technology was not evaluated in this study despite its mention in the literature.

On another note, various software was required for nearly all developmental mathematics courses. Although the specific software names were captured, they were reviewed only as contextual information about the courses and semesters during which they were assigned. Many but not all software captured from the course syllabi also were cited in various literature about technology-mediated developmental mathematics courses in Chapter 2. For informational purposes, Table 4 contains the software required in the respective developmental mathematics courses for specified semesters.

Table 4

Software Used for Developmental Mathematics Courses by Semester

Software	Developmental Mathematics Course Codes and Semester Ranges							
	0112	0212	0331	0332	0333	N014	N024	N032
ALEKS					Fa 17- Fa 19	Fa 17- Sp 18, Fa 19	Fa 17- Sp 18, Fa 19	Fa 17- Sp 18, Sp 19- Fa 19
Hawkes Learning System		Fa 15	Sp 14- Fa 16					
Knewton						Fa 18- Sp 19	Fa 18- Sp 19	
MathXL	Fa 16							
MyLabsPlus			Fa 11- Su 13	Fa 11- Su 13				

(continued)

Software	Developmental Mathematics Course Codes and Semester Ranges							
	0112	0212	0331	0332	0333	N014	N024	N032
MyMathLab		Fa 16	Fa 13	Fa 13-Su 14, Sp 17-Su 17				

Note. For brevity, semesters were abbreviated such that "Fa" was Fall, "Sp" was Spring, and "Su" was Summer.

Research Question 1

To address the first research question, technology use and student performance in developmental mathematics courses were explored. Before testing for an association between the two variables, student performance in developmental mathematics was first investigated. All 9,283 student participants enrolled in at least one developmental mathematics course during the timeframe consistent with the archival data used in the study. Initially, it was expected data would be available to allow for calculating the average number of attempts a student required before they passed a developmental or gatekeeper mathematics course; however, only semester and grade information related to a student's final course attempt were accessible. Despite this, it was possible to compute the number of developmental and gatekeeper mathematics courses each student took.

Overall, students took a mean of 1.12 (*SD* = 0.35) developmental mathematics courses, wherein students took between one and four courses. Some students took more developmental mathematics courses than others because they required two levels of mathematics instruction, specifically MATH 0331 (Developmental Mathematics) and MATH 0332 (Developmental Mathematics II). Others took more than one type of developmental mathematics course, such as the accelerated MATH 0112 or 0333 courses or the corequisite courses MATH N014, N024, or N032. Among those students who enrolled in three or four developmental mathematics courses, they often did not pass a course and reenrolled the next semester, again not passing the course. There were some instances in which a student passed the first level but not the second level of developmental mathematics, later successfully completing an accelerated or corequisite course. There was also a small number of students who took one or more corequisite courses they did not pass and later earned credit in a different corequisite course and completed the paired gatekeeper mathematics course. Most students (88.7%, *n* = 8,238) took one course, another 10.6% (*n* = 986) took two, and 60 students (0.6%) each took three or four developmental mathematics courses. Because students had the ability to enroll in more than one course (because they either needed more than one level of instruction or took different courses after not passing one or more of them), the number of total instances of developmental mathematics courses taken was larger than the number of participants. In all, there were 10,391 instances of developmental mathematics courses taken, which is presented by course in Table 5. This number served as the base size for evaluating student performance and the association to technology use in developmental mathematics courses.

Table 5

Count and Percentage of Student Enrollment in Developmental Mathematics Courses

Course	Enrollment	
	N	%
MATH 0112	307	3.0
MATH 0212	104	1.0
MATH 0331	1,205	11.6
MATH 0332	6,514	62.7
MATH 0333	1,316	12.7
MATH N014	375	3.6
MATH N024	199	1.9
MATH N032	371	3.6

The developmental mathematics courses included in the study were graded on two different bases. Students who took MATH 0331 and 0332 were scored on a traditional 5-letter grading system, with grade points from 0.0 to 4.0 corresponding to the respective letters. The mean GPA for MATH 0331 was 2.15 (*SD* = 1.36) and MATH 0332 was 2.15 (*SD* = 1.40). Grading for MATH 0112, 0212, 0333, N014, N024, and N032 was on a credit (CR) and no credit (NC) basis. It is worth noting that completed courses in developmental education are neither counted toward a student’s program requirements nor included in their total credit hours for determining graduation or classification status (SHSU, 2020b). Additionally, grade points earned in developmental education courses are not calculated into students' overall GPA (SHSU, 2015). For these reasons, student performance in all developmental mathematics coursework was analyzed on a credit/no credit basis, and grades for MATH 0331 and 0332 were recoded, as appropriately.

As per course policies noted in syllabi for these two courses, students had to earn a C or better to receive credit and advance either to the next developmental mathematics course or a gatekeeper mathematics course. Thus, students' grades of D or F were changed to NC and A, B, and C grades became CR. Table 6 includes the percentage of students who earned credit for developmental mathematics both overall and by specific course. Overall, 76.8% (*n* = 7,978) of students earned credit and 23.2% (*n* = 2,413) did not earn credit for developmental mathematics courses. Of note, cases in which a student's grade was missing or displayed as audit (AU), Q-drop (Q), or withdrawn (W) were not included. Consistent with the I-E-O model, student performance identified as CR or NC was the outcomes variable.

Table 6

Counts and Percentages of Student Credit Status in Developmental Mathematics Courses

Course	CR		NC	
	N	%	*N*	%
MATH 0112	191	62.2	116	37.8
MATH 0212	49	47.1	55	52.9

(continued)

Course	CR		NC	
	N	%	*N*	%
MATH 0331	924	76.7	281	23.3
MATH 0332	4,975	76.4	1,539	23.6
MATH 0333	1,007	76.5	309	23.5
MATH N014	326	86.9	49	13.1
MATH N024	171	85.9	28	14.1
MATH N032	335	90.3	36	9.7

The primary step to answering the research question was to conduct a chi-square test of association between the environmental (i.e., technology) and outcome (i.e., student performance) variables using SPSS. Consistent with the requirements of chi-square, both variables were nominal. The chi-square test was performed to evaluate whether an association existed between technology use, in general, and students' credit status in all developmental mathematics courses. The results indicated that there was a statistical relationship between technology use overall and students' credit status in the courses ($\chi^2(1) = 38.34$, $p < .001$, $\phi = -.06$). The effect size as computed using Phi (ϕ) and, as per interpretations proposed by Cohen (1988), indicated the strength of the association was small and thus, was considered weak. The resulting value for Phi (ϕ) appeared negative in the SPSS output because of the coding values assigned to the technology variable. Thus, the negative sign was not interpreted as a negative association.

Although the results of chi-square analysis did not indicate directionality of the statistically significant association, cross-tabulations between students' credit status and technology use in developmental mathematics courses helped to illuminate the relationship. Observed and expected counts of the cross-tabulations were organized into a two-by-two contingency table. These values differed, hence the statistically significant result of chi-square. Among the 10,391 instances of developmental mathematics courses taken, technology was used most of the time (98.4%). The greatest number of observed counts (n = 7,818) and percentages (75.2%) of these instances corresponded to those who earned credit in the technology-enhanced courses. Although this, at first, appeared to suggest a positive association between technology use and students' earning course credit, review of the observed and expected values suggested differently. The observed values for technology use were lower than the expected counts. In other words, there were fewer than expected students who earned credit and more than expected students who received no credit for the technology-enhanced developmental mathematics courses. Thus, a slightly negative association was suggested by this examination of the contingency table.

The chi-square test was repeated to understand better with which developmental mathematics course the statistically significant association with technology existed. Because six of the eight courses were available only as technology-enhanced courses, these were not evaluated because the technology variable was a constant. Two courses—MATH 0112 and MATH N032—were eligible for further evaluation. With respect to MATH 0112, the association between technology use and students' credit status was not statistically significant ($\chi^2(1) = 2.46$, $p = .12$); however, there was a statistically significant association between the variables in MATH N032 ($\chi^2(1) = 14.13$, $p < .001$, $\phi = -.20$).

Unlike the association between developmental mathematics courses and overall technology use, the association for MATH N032 was close to medium strength. Given the statistically significant association discovered within MATH N032, a two-by-two contingency table was created. Among the 371 students who took this course, most (48.2%) earned credit in a technology-enhanced section of the course; however, 42.0% earned credit in the non-technology-enhanced section. The observed and expected values were identical for those who earned a CR or NC in the technology-enhanced course, meaning these students were no more or less likely to pass the course. Conversely, fewer than expected students earned an NC and more than expected students earned a CR in the non-technology-enhanced sections of MATH N032. This result was interpreted as a statistically significant positive association for students who took the non-technology-enhanced course. Thus, the association between technology use and student performance in MATH N032 related only to the non-technology-enhanced course sections.

The second step in evaluating student performance and technology use in developmental mathematics courses was to perform the chi-square test of association for each of the seven technologies addressed in this study. Overall, more students by count ($n = 7{,}978$) and percentage (76.8%) earned credit for developmental mathematics coursework than did not. Further, more students by count ($n = 7{,}103$) and percentage (89.0%) earned credit in courses in which technology was used. This was consistent across the technologies explored, with the exceptions of scientific calculators, the learning management system, and online supplements. Although there was a higher number of students who earned credit in developmental mathematics in which these three technologies were not listed in course syllabi, the proportion of students' earning credit in technology-enhanced versus non-technology-enhanced courses remained within the 70% range for each.

These percentages also were consistent with the reduced frequency that these technologies were reported in syllabi. Among the seven technologies and 10,391 course instances, online homework was used the most (*n* = 10,132), followed by graphing calculators (*n* = 9,401), software (*n* = 7,978), scientific calculators (*n* = 7,578), e-textbooks (*n* = 7,159), and the learning management system (*n* = 3,395). Online supplements were reportedly used the least (*n* = 118). Indeed, only some instances of MATH 0112 and MATH 0212 syllabi referenced using online modules, podcasts, or websites. These results are detailed as a cross-tabulation of students' credit status for all developmental mathematics courses in Table 7.

Table 7

Cross-tabulation of Students' Credit Status Related to the Use of Specific Technologies

Technology	Use	Credit Status	
		CR	NC
Graphing calculator	Yes	7,103	2,298
	No	875	115
Scientific calculator	Yes	1,155	423
	No	6,823	1,990

(continued)

Technology	Use	Credit Status	
		CR	NC
Learning management system	Yes	2,434	961
	No	5,544	1,452
Online homework	Yes	7,736	2,396
	No	242	17
Software	Yes	7,685	293
	No	2,323	90
Online supplements	Yes	95	23
	No	7,883	2,390
E-textbook	Yes	5,190	1,969
	No	2,788	444

Additionally, the results of the chi-square tests regarding the seven technologies are exhibited in Table 8. For all but two technology forms (online supplements and software), there were statistically significant associations, all of which had small effect sizes and thus, weak associations.

Table 8

Results of Chi-Square Tests of Association between Course Credit Status and Technologies Used in All Developmental Mathematics Courses

Technology	χ^2	p	Φ
Graphing calculator	82.67	< .001	-.09
Scientific calculator	13.41	< .001	-.04
Learning management system	73.11	< .001	-.08
Online homework	41.34	< .001	-.06
Software	0.02	.90	.001
Online supplements	0.93	.33	.01
E-textbook	236.68	< .001	-.15

Note. Degrees of freedom was one ($df = 1$). Statistically significant findings were noted where $p < .05$.

Among the five technologies for which statistically significant associations resulted, observed and expected counts in contingency tables were reviewed as well as comparisons of the percentages of students who earned credit in developmental mathematics courses in relation to each of these technologies. As with overall technology use, the statistically significant associations appeared somewhat negative due to the differences in observed and expected values. For all five technologies, the observed counts of CR grades earned by students in the technology-enhanced courses were lower than expected and the NC grades were more than expected. The differences in counts also ranged from smallest, as with e-textbooks and online homework, to largest, as with the learning management system. Forty-four fewer students earned credit in courses with e-textbook and online homework integration, and 173 fewer students earned credit in courses using in which the learning management system was used. The lower-than-expected counts among those with technology use corresponded to more than expected students earning credit in courses in which each of the five technologies were not used.

Additional analyses were performed for each developmental mathematics course to evaluate whether associations between the specific technologies used and student performance existed within each course. Only MATH 0112, 0331, 0332, 0333, N014, and N032 exhibited statistically significant results. For MATH 0112, student performance was statistically significantly and moderately associated with graphing calculators ($\chi^2(1) = 24.93$, $p < .001$, $\varphi = -.29$), scientific calculators ($\chi^2(1) = 24.93$, $p < .001$, $\varphi = -.29$), learning management system ($\chi^2(1) = 24.93$, $p < .001$, $\varphi = -.29$), online homework ($\chi^2(1) = 24.93$, $p < .001$, $\varphi = -.29$), online supplements ($\chi^2(1) = 41.60$, $p < .001$, $\varphi = .37$), and e-textbooks ($\chi^2(1) = 34.71$, $p < .001$, $\varphi = -.34$). A review of the observed and expected counts indicated the associations trended negatively among students in MATH 0112 courses in which graphing calculators, scientific calculators, a learning management system, online homework, and e-textbooks were used. Fewer than expected students earned credit in the courses in which these five technologies were used, while more than expected students earned an NC. Conversely, more students than expected earned credit when software and online supplements were used in MATH 0112, suggesting a positive association.

Learning management systems were statistically significantly and weakly associated with student performance in MATH 0331 ($\chi^2(1) = 5.25$, $p = .02$, $\varphi = -.07$), MATH 0332 ($\chi^2(1) = 178.56$, $p < .001$, $\varphi = -.17$), and MATH 0333 ($\chi^2(1) = 16.23$, $p < .001$, $\varphi = .11$). Observed and expected counts again differed. Fewer than expected students earned credit in the three courses in which a learning management system was used and more than expected students earned credit when a learning management system was not used. The association between learning management system use in MATH 0331, MATH 0332, and MATH 0333 were considered to be weakly, negatively, statistically significantly associated. E-textbooks also were statistically significantly and weakly associated with student performance in MATH 0331 ($\chi^2(1) = 22.35$, $p < .001$, $\varphi = -.14$), MATH 0332 ($\chi^2(1) = 99.82$, $p < .001$, $\varphi = -.12$), and MATH 0333 ($\chi^2(1) = 64.26$, $p < .001$, $\varphi = -.22$). These associations appeared negative as the observed counts were less than expected for students earning credit in the course sections in which e-textbooks were used compared to the courses in which e-textbooks were not used. Finally, MATH N032 exhibited a weak statistically significant association with online homework ($\chi^2(1) = 14.13$, $p < .001$, $\varphi = -.20$) and software ($\chi^2(1) = 14.13$, $p < .001$, $\varphi = -.20$). Both statistically significant associations trended negatively with fewer than expected students earning credit in MATH N032 when online homework and software were incorporated.

Research Question 2

Among the 9,283 students who took at least one developmental mathematics course, 6,009 also enrolled in at least one entry-level, college mathematics course. On average, students took 1.25 (*SD* = 0.52) gatekeeper mathematics courses. Although most students (79.1%, *n* = 4,753) took only one course, another 17.6% (*n* = 1,060) took two, 2.8% (*n* = 169) of students took three, and 27 students (0.4%) took four or more college-level mathematics courses. Like with the developmental mathematics courses, students' ability to take more than one gatekeeper mathematics course meant there were more instances of enrollment in these courses compared to the number of students. Specifically, there were 7,490 instances, which was considered the base size for exploring student performance in gatekeeper mathematics courses. Table 9 displays the number of students who took each of the 10 mathematics courses included in the analysis. For ease, the course codes and titles were included.

Table 9

Counts and Percentages of Total Instances for Gatekeeper Mathematics Course

Course	*N*	%
MATH 1314: Pre Calculus Algebra	1,564	20.9
MATH 1316: Plane Trigonometry	371	5.0
MATH 1324: Mathematics for Managerial Decision Making	1,092	14.6
MATH 1332: College Mathematics	2,972	39.7

(continued)

Course	*N*	%
MATH 1369: Elementary Statistics	421	5.6
MATH 1384: Introduction to Foundations of Math I	479	6.4
MATH 1410: Elementary Functions	199	2.7
MATH 1420: Calculus I	152	2.0
PHIL 2352: Introduction to Contemporary Logic	30	0.4
STAT 1369: Elementary Statistics	210	2.8

All gatekeeper mathematics courses included in the study were graded using a 5-letter system with the respective grade points ranging from 0.0 to 4.0. Students earned a mean GPA of 2.19 (*SD* = 1.21). Nearly three-fourths (72.9%) of students earned a C or better in the gatekeeper mathematics courses, translating into 15.3% (*n* = 1,145) who earned an A, 27.3% (*n* = 2,046) earned a B, and a C was earned by 30.3% (*n* = 2,272) of students. Grades of D and F were earned by the remaining 27.1% (*n* = 2,027) of students. For a distribution of the letter grades for each of the gatekeeper mathematics courses, see Appendix D. The mean GPA for each gatekeeper mathematics course was calculated and is presented in Table 10.

Table 10

Descriptive Statistics for Gatekeeper Mathematics Courses

Course	*M*	*SD*
MATH 1314	1.96	1.27
MATH 1316	2.03	1.22
MATH 1324	2.07	1.17
MATH 1332	2.31	1.19
MATH 1369	2.40	1.28
MATH 1384	2.56	.90
MATH 1410	1.90	1.25
MATH 1420	1.91	1.19
PHIL 2352	1.70	1.44
STAT 1369	2.47	1.21

Using a one-way ANOVA, it was determined mean GPAs were statistically significantly different between the gatekeeper mathematics courses ($F(9, 7480) = 22.18$, $p < .001$) with a large effect size ($\eta^2 = .20$). Post hoc testing via Tukey Honest Significant Difference (HSD) was performed to generate more insight into the differences, which were present for nearly every course pair. The breakdown of statistically significant differences between each course pair is displayed in Appendix E.

In pursuit of an answer to the second research question, the focus turned to exploring the association between technology use in developmental mathematics and the grades students earned in gatekeeper mathematics courses. Chi-square tests of association again were performed. First, technology use as a yes or no binary variable was evaluated against the five letter grades. Overall, there was not a statistically significant association between overall technology use in developmental mathematics courses and letter grades earned by students in the gatekeeper mathematics courses ($\chi^2(4) = 2.93$, $p = .57$). Further, the seven technologies were reviewed in relation to students' grades. The participants were exposed more frequently to technology-enhanced developmental mathematics courses overall, which varied by the forms of technology. Only the learning management system and online supplements were used least often among gatekeeper mathematics course takers. These results are presented in Table 11.

Table 11

Grades Earned in Gatekeeper Mathematics Courses by Technology Form

Technology	Used	Letter Grade				
		A	B	C	D	F
Graphing calculator	Yes	1,140	2,034	2,256	1,139	876
	No	5	12	16	7	5
Scientific calculator	Yes	1,102	1,987	2,186	1,114	839
	No	350	535	650	326	226

(continued)

Technology	Used	Letter Grade				
		A	B	C	D	F
Learning management system	Yes	350	535	650	326	226
	No	795	1,511	1,622	820	655
Online homework	Yes	1,140	2,034	2,256	1,139	876
	No	5	12	16	7	5
Software	Yes	1,113	1,998	2,199	1,146	844
	No	32	48	73	32	37
Online supplements	Yes	11	25	40	21	21
	No	1,134	2,021	2,232	1,125	860
E-textbook	Yes	939	1,646	1,813	962	717
	No	206	400	459	184	164

Chi-square was calculated then for the seven technologies related to the student performance variable (i.e., letter grade) for this research question. Statistically significant associations with small effect sizes and of weak association, as found using Cramer's V, were found with two of the seven technologies: learning management system and e-textbooks. No statistically significant associations were discovered for the remaining five technologies. Table 12 includes these findings.

Table 12

Results of Chi-Square Tests of Association between Technologies Used in Developmental Mathematics Courses and Letter Grades Earned in Gatekeeper Mathematics Courses

Technology	χ^2	p	V
Graphing calculator	0.95	.92	.01
Scientific calculator	8.96	.06	.04
Learning management system	10.12	.04	.04
Online homework	0.95	.92	.01
Software	8.12	.09	.03
Online supplements	9.14	.06	.04
E-textbook	9.80	.04	.04

Note. Degrees of freedom was four ($df = 4$). Statistically significant findings were noted where $p < .05$.

Review of the observed and expected counts for learning management system use in developmental mathematics courses suggested the statistically significant association was positive. More students than expected earned a grade of A, B, or C in gatekeeper mathematics courses following completion of developmental mathematics courses in which a learning management system was incorporated. On the other hand, fewer than expected students earned an A, B, or C in gatekeeper mathematics courses after taking a developmental mathematics course in which e-textbooks were used. This difference in observed and expected counts indicated a negative association.

Additional analyses were conducted to explore whether the statistically significant associations for learning management systems and e-textbooks occurred in relation to any particular developmental or gatekeeper mathematics courses taken by the students. No statistically significant associations were found between learning management systems or e-textbooks and students' letter grades across the 10 gatekeeper mathematics courses; however, a statistically significant association was identified in relation to e-textbooks and MATH 0332 ($\chi^2(4) = 11.39$, $p = .02$). A calculation of Cramer's V ($V = .04$) indicated this was a weak association. Thus, the grades earned in gatekeeper mathematics courses by students who took MATH 0332 when e-textbooks were used, exhibited a weak statistically significant association. A comparison of observed and expected counts suggested the association was slightly negative as fewer than expected students earned a grade of A, B, or C in gatekeeper mathematics courses. Indeed, more than expected students earned these higher grades in MATH 0332 when e-textbooks were not used.

No other developmental or gatekeeper mathematics courses exhibited statistically significant associations with learning management systems, which is presented in the table in Appendix F or e-textbooks, which is displayed in Appendix G. Course pairs also were analyzed, of which no statistically significant associations were discovered regarding either learning management systems or e-textbooks. A detailed table containing these findings for each developmental-gatekeeper mathematics course pair related to learning management systems and e-textbooks appear in Appendix H and Appendix I, respectively.

Summary

Within this chapter, the results of the dissertation study were presented. Descriptive statistics and frequencies were computed to understand the demographic and academic backgrounds of the developmental mathematics students who were the study participants. Chi-square tests of association were performed for two research questions related to exploring whether technology use in developmental mathematics courses was associated with student performance in developmental and gatekeeper mathematics courses. Chapter 5 includes discussion of the results of the study as well as implications of these findings, implications for policy and practice, and recommendations for future research and practice.

CHAPTER V

Discussion

The purpose of this dissertation study was two-fold. First, it was developed as an exploration of technology use in developmental education, especially as it relates to student performance. The study also was developed considering various Texas policies, including the *2012-2017 Statewide Developmental Education Plan*, which broadly have directed higher education institutions to incorporate technology into developmental education courses and programs. Second, this study was aimed at addressing a gap in the literature relevant to relationships between technology and student performance in developmental education and, more specifically, developmental mathematics. Despite a plethora of literature detailing examples of technology used in developmental mathematics courses and studies in which student performance findings, such as pass rates, were presented, there remained a gap connecting technology use and student performance.

Applying Astin's (1991) I-E-O model and background from student involvement theory, the study included two research questions. Inputs were defined as students' prior mathematics knowledge, a descriptive variable collected from students' scores on the Texas Success Initiative Assessment (TSIA). Technology use, both in general and as seven technologies gleaned from the literature, were established as the environment variable. Finally, outcomes were student performance, identified as students' credit status in developmental mathematics course for the first research question and letter grades earned in gatekeeper mathematics courses for the second research question.

Review of the Research Questions and Results

A review of the data collected for this study included descriptive statistics and frequencies of student characteristics as well as chi-square tests of association to illuminate whether relationships existed between technology use and student performance. The first area of data analysis included a review of student characteristics. Most student participants were female, of diverse ethnic backgrounds, and were found to be equally first-time-in-college and non-first-time-in-college students. The next area was of the relevant mathematics. There were eight developmental and 10 gatekeeper mathematics courses included in the study.

The courses involved traditional, sequential developmental mathematics courses offered in earlier semesters and accelerated, corequisite courses offered in more recent academic years. Gatekeeper mathematics courses ranged in subject title and content. Specific gatekeeper mathematics courses taken by the students often was influenced by their undergraduate major because programs required specific mathematics courses to be taken. At both the developmental and gatekeeper levels, nearly three-fourths of students earned course credit in the developmental mathematics course or received a grade of C or better in the gatekeeper mathematics course. This dissertation study was driven by two research questions.

1. How does student performance in developmental mathematics courses relate to the integration of technology in developmental mathematics courses?
2. How does student performance in gatekeeper mathematics courses relate to technology use in developmental mathematics courses?

To analyze study data to address these questions, the chi-square test of association was used. First, statistically significant associations were discovered in relation to overall technology use and student performance, defined in the first question as students' earning credit for the developmental mathematics course. Contingency tables of observed and expected counts suggested this association was slightly negative. Only one course, MATH N032, which is a corequisite course affiliated with MATH 1332, "College Mathematics," exhibited a statistically significant association between students' credit status and technology use overall. A review of the relevant contingency table indicated a negative association.

Among the seven technologies explored, all but software and online supplements exhibited statistically significant associations with student performance in developmental mathematics courses. Again, the association was considered weak and negative with fewer than expected students earning credit in developmental mathematics courses in which the five technologies were used. Of the eight developmental mathematics courses included in the study, technology integration in five of the courses were statistically significantly associated with students' earned credit and with one or more forms of technology. Some of the associations were of moderate strength, but most were weak, and nearly all were negative associations. Only the use of software and online supplements in MATH 0112 were positively associated.

Regarding the second research question about student performance in gatekeeper mathematics courses and technology use in developmental mathematics courses, a statistically significant association was not discovered for technology use overall. When investigating the relationship between student performance and the seven technologies, however, two of them—learning management systems and e-textbooks—indicated a statistically significant association. The observed and expected counts suggested a positive association between learning management systems and a negative association between e-textbooks and students' letter grades earned in the gatekeeper mathematics courses. Among the eight developmental and 10 gatekeeper mathematics courses, only one course, MATH 0332, known as "Developmental Mathematics II," was found to have a statistically significant association between e-textbook use and gatekeeper mathematics course grades. This association was considered weak and slightly negative. No other statistically significant relationships resulted between student performance and other technologies, by developmental or gatekeeper mathematics courses, or for pairs of developmental and gatekeeper mathematics courses.

The answers to the two research questions denoted some statistically significant associations were found. As such, the null hypotheses, which were stated in Chapter 3 as there being no statistically significant associations between student performance in either developmental or gatekeeper mathematics courses and technology use in developmental mathematics courses, were rejected. Whether students earned credit in developmental mathematics courses was statistically significantly, weakly, and negatively associated with overall technology use in the courses as well as moderately and negatively associated with the use of graphing calculators, scientific calculators, learning management systems, online homework, and e-textbooks. Additionally, students' letter grades earned in gatekeeper mathematics courses were not statistically significantly associated with overall technology use in developmental mathematics courses, but their grades were statistically significantly, albeit weakly and negatively, associated with learning management system and e-textbook use in developmental mathematics courses.

In reviewing the results, it was necessary to consider a potential caveat to their interpretations related to the instructional model of the developmental mathematics courses at the institutional setting for the study. In 2017, the State of Texas implemented policies from House Bill 2223 of the 85th Texas Legislature, requiring a shift in developmental education courses to corequisite course models (Signed by Governor Abbott on June 10, 2017). This policy marked a shift away from traditional course sequences to corequisite approaches to teaching developmental education throughout the state. At the institution involved in this study, developmental mathematics courses changed to the corequisite MATH N014, MATH N024, and MATH N032, alongside an accelerated course, MATH 0333, with all other developmental mathematics courses eliminated. This change was not fully complete, however, as the state gave institutions time to scale-up corequisite courses. One-quarter of students were to be enrolled in corequisite developmental education by 2018, half of students by 2019, 75% by 2020, and all students must be enrolled in corequisite courses beginning with the 2021 to 2022 academic year and after (19 Tex. Admin. Code, § 4.62, 2020).

Such a shift would not be without its challenges. Issues with corequisite courses included that the model had not been beneficial among those students considered to be most underprepared, having scored the lowest on placement assessments (Smith, 2017), and that more resources, especially financial, were needed to be implemented (Belfield et al., 2016). Still, a radical change involving the merging of two levels of mathematics content, coupled with differences in corequisite models among institutions continued to pose challenges. In a pilot of corequisite courses at Austin Community College, there was difficulty in figuring out which developmental mathematics instructors would be qualified to teach the new, corequisite courses (Smith, 2017). Notably, the academic credentials for teaching developmental and college-level mathematics courses differed. Adjunct instructors teaching developmental mathematics needed to have, at minimum, a master's degree, while college-level mathematics instructors needed a doctorate. Although some faculty held sufficient qualifications to teach at both levels, others did not (Smith, 2017).

On the other hand, corequisite courses in other studies or states suggested benefits. For instance, Denley (2016) reported that 12.3% of students in Tennessee who completed traditional developmental mathematics courses had later passed a gatekeeper mathematics course, which increased to 54.8% among students who completed corequisite developmental mathematics courses. In a randomized controlled trial, Logue et al. (2019) found developmental mathematics students exposed to corequisite courses had statistically significantly higher pass rates compared to those enrolled in traditional courses. These successes also carried over to their completion of general education degree requirements and graduation rates (Logue et al., 2019).

Absent from these examples and others across the literature, however, was the role of technology. Following the state policy change to corequisite developmental education courses, the three corequisite courses—MATH N014, N024, and N032—were implemented. Among these corequisite courses, technology use varied, as found in this study. Overall, technology was used in sections of all three courses, and three types of technology were reported in course syllabi: a learning management system, online homework, and software. Of the three courses, MATH N032 was the only corequisite mathematics course with course sections in which technology was not integrated compared with MATH N014 and N024 in which technology was consistently reported. Although the number of participants from Fall 2017 to Fall 2019 who were enrolled in corequisite developmental mathematics courses was small (n = 945, 9.1%), it cannot be ignored that the results of this study could have varied among pre- and post-2017 developmental mathematics courses.

This limitation on the interpretation of study results also must be considered because course syllabi for the college-level mathematics courses connected to each of the corequisite developmental mathematics courses were not reviewed. Thus, technology use in the gatekeeper mathematics courses may have been consistent with or differed in overall technology use, the types of technology incorporated, and the strategies used to integrate the technology. Such limitation allowed for speculation that differences might have existed, especially in MATH N032 as the lone corequisite course with differences in overall technology use and statistically significant associations with online homework and software. This limitation aside, the results of this study exhibited connections to the literature and conceptual frameworks, had implications for policy and practice, indicated opportunities for future research, and offered recommendations for practice.

Relationships to the Literature

Primarily, this study’s relationship with the literature was one of expansion and, ideally, contributed to addressing a gap about the relationship of technology to developmental mathematics students’ performance. Other elements of the study also were connected to the literature. For instance, describing the students in terms of their role as first-in-time-college (FTIC) students related to research by Abraham et al. (2014) in which student performance, defined as earning a C or better in a college-level mathematics course after scoring below college readiness standards in Texas, was evaluated. Students' FTIC status was not directly related to the research questions of this study; however, the percentage of FTIC students included in the study was lower than the percentage of FTIC students who were below college readiness standards in mathematics in the Abraham et al. (2014) study.

The smaller percentage of FTIC students at this institution might be reflective of a greater number of students who transferred from other institutions to this one. For instance, students who took courses at a community college to address prerequisites would not be considered FTIC students even though their enrollment in developmental mathematics courses at this university marked their first time attending a four-year institution or taking any mathematics coursework. Students who elected for the Academic Fresh Start Program after not attending college-level coursework for 10 or more years also would not be considered FTIC (SHSU, n.d.). These differences among students' academic backgrounds may account for differences in the percentage of FTIC students in this study compared to the Abraham et al. (2014) study.

Perhaps the strongest connection between this study and the literature was the technology. Discussed in detail in the literature review, the technology considered for this study was identified primarily from the literature. As noted, the works of Cederholm (2010) and Natow et al. (2017) helped to establish the boundaries on the types of technologies considered in this study. Technology was defined as being used to support instruction (Cederholm, 2010). Natow et al. (2017) published findings of interviews with college leaders about the types of technology integrated into their developmental education programs. From the authors' study, three categories of technology were identified: instructional technology like software, course management technology such as learning management systems, and student support technology like early alert systems. Consistent with the work of Natow et al. (2017), similar examples of technology were identified in the course syllabi reviewed for this research. Further relationships between the results of this study and literature on the subject related to the conceptual framework, policy, and practice, which will be discussed.

Insights from the Conceptual Framework

The conceptual framework informed identification of the study variables and promoted understanding of how relationships between and among the inputs, environment, and outcomes. For this study, inputs were students' scores earned on the TSIA as a descriptive variable for students' prior mathematics knowledge. The environment consisted of technology both broadly investigated and as seven forms of technology based in the literature. Finally, outcomes were student performance variables for credit earned in developmental mathematics courses and letter grades received in gatekeeper, or entry-level college mathematics courses.

Beyond using the framework to guide defining of study variables, it promoted an understanding of the interrelationships and multidimensionality of the model components as highlighted by Astin (1991). Further, this study joined other adaptations of the I-E-O model, such as Norwani et al. (2009) who studied environmental effects on learning outcomes and Keller's (2011) study about student success in developmental mathematics. The model also facilitated using inputs as a descriptive variable only while investigating the relationship between the environment and outcomes variables. Such an approach was made possible by the flexible and practical capabilities of the model, also apparent in research by Addams (2013) who noted that inputs could be defined beyond students' personal characteristics or experiences, as done in this study.

Finally, using one variable in a descriptive sense while evaluating the relationship between the other two components of the model was consistent with the work of Judd and Keith (2012). The authors suggested two or three components could be explored while using the I-E-O model, also opening the range of possible data analyses, including approaches to study correlations, associations, covariance, and more. Indeed, other forms of data analysis could be included in recommendations for future practice.

Implications for Policy and Practice

Much of the purpose of this study was influenced by various developmental policies existing in the State of Texas. Thus far, developmental education programs have been addressed through house bills passed by the state legislature requiring mandatory technology use, a shift from sequential developmental education courses to accelerated and corequisite course designs, and assessment of students' college readiness using the TSIA, now the TSIA2. Burns and Schuller (2007) argued lawmakers who pass such policies must have evidence to inform their decisions. As such, this study served as additional insight into developmental education both broadly and, more specifically, for developmental mathematics coursework and technology-mediated approaches. Changes to Texas Administrative Code and Texas Education Code, the *Statewide Developmental Education Plan*—namely the 2012-2017 version—also informed this study and, in response, the results of this study and future research potentially influenced by the findings may enable such laws and plans to be better informed.

Other implications centered about the practice of incorporating technology into developmental mathematics courses. Practice may shift toward using or eliminating certain technologies in developmental mathematics teaching and learning based upon interpretations of these results. For instance, statistically significant associations identified between students' earning credit or passing grades and e-textbooks in developmental and gatekeeper mathematics courses, may contribute to developmental education administrators or educators opting to incorporate e-textbooks more frequently. Another possibility might be increasing the use of online supplements or expanding upon the online supplements included given their minimal use observed in this study.

What is further gleaned from the results of this study that relate to both policy and practice is that merely requiring technology use, as in the state mandate, reporting its use, such as in course syllabi, or the existence of statistically significant associations between technology use and student performance served as only a start. The key for future study, for instance, must not be focused just on ascertaining whether technology, broadly considered or regarding specific types of technology, are used but *how* they are used. For instance, students' credit status in the corequisite developmental mathematics course MATH N032 was negatively associated with technology use overall. Indeed, what might be important to the practice of technology integration is how technology was used and the relationship to the college-level, gatekeeper mathematics course MATH 1332.

Further, there may be other explanations for the statistically significant associations that, upon reflection, may address benefits and challenges of technology integration. For example, students' lack of familiarity with, knowledge about how to use, or access to a graphing calculator, or access to and literacy with a computer to engage with the learning management system or complete online homework may be involved. Indeed, with each association, positive or negative, there is an opportunity to explore the practice of technology integration and consider, in the future, how these practices may be applied or improved to meet the needs of students and instructors alike. These very considerations and interpretations offered opportunities for future research and suggested recommendations for future practice.

Recommendations for Future Research and Practice

The findings of this dissertation study indicated relationships existed between technology use in developmental mathematics and student performance in developmental and gatekeeper mathematics courses. The study focused on seven specific technologies and included focused definitions for student performance as course credit at the developmental level and letter grades, especially a C or better, at the gatekeeper, college-level. There are a wide range of other technologies and definitions of student performance that could be explored in future investigations. For instance, technology focused on instructional and course management technologies, presented by Natow et al. (2017); however, student support technology like early alert systems and online tutoring—for which some data were observed in course syllabi—could be reviewed. Student performance could also be defined differently, such as students' overall GPA, persistence rates, time to degree completion, graduation rates, and more.

Additional recommendations for future research might relate, not to the environment or outcomes, but to the inputs. For example, affective characteristics of developmental mathematics students could be included. Jacobson (2006) discussed technology literacy, Kim and Hodges (2012) studied student motivation, Leong and Alexander (2014) were concerned with student attitudes, Prescott (2017) referenced self-efficacy, and Heiberger and Harper (2008) and Henrie et al. (2015) discussed student engagement. Math anxiety is yet another student characteristic that may prove meaningful as an input in future research. This affective factor was found in works by Taylor and Galligan (2006), Taylor (2008), and Tatar et al. (2015).

Of particular interest was research by Tatar et al. (2015) who considered math anxiety in relation to technology use in mathematics courses and computer literacy. Unlike other recommendations for future research presented, the authors' research focused not on students but on instructors. Indeed, Zientek et al. (2015) studied faculty preferences for technology use. Although technologies reported in course syllabi might be reflective of faculty involved in teaching developmental mathematics, the study did not explicitly explore faculty inputs. Future research, however, could expand upon this study to explore the role of faculty regarding technology literacy or review the work of Skidmore et al. (2014) who studied developmental educators' generational status and technology use in teaching developmental education courses.

A final area with potential for future research given this study is the role and effectiveness of technology use in developmental mathematics—or, more generally, developmental education—amid the COVID-19 pandemic. With many institutions shifting courses to hybrid and online modes, the university setting for this study included, there is much to explore. Most course syllabi reviewed for this study indicated developmental mathematics courses were predominately, though not exclusively, offered as face-to-face courses. In the time of a pandemic, however, the traditional in-person class has been replaced by courses hosted via learning management systems, lectures replaced by Zoom meetings, and assessments shifted to remote proctoring (Bickerstaff et al., 2021).

Further, with technology at the center of delivering higher education, issues related to equitable access to necessary technologies by students (de los Santos et al., 2021), instructors' use of technological gadgets (Ali, 2020), adaptations of teaching and learning processes from face-to-face to virtual environments (Shenoy et al., 2020), and digital readiness and socioemotional perceptions of students (Handel et al., 2020) are emerging. Each of these topics would expand upon this study, enabling further discussion and study about what technologies are beneficial to developmental education students and promote quality student performance.

Although expanding upon this study and conducting future research about technology integration in developmental mathematics serves to enhance future practice, the findings of this study also illuminated some recommendations. Given the negative statistically significant associations with graphing calculators in developmental mathematics courses, practices should include more accessible alternatives. Online resources, such as websites with graphing applications, or more thorough instruction on how to use graphing calculators should be made available to students. Similar instruction for students and training for instructors should be incorporated for learning management systems. As described in this study, Blackboard was the learning management system used in all eight developmental mathematics courses. More training for users and access to support materials would help to familiarize them with Blackboard. Students could learn how to access course documents, and instructors could become acquainted with designing their course sites and supplying timely feedback or responses to students' questions through Blackboard's communication features.

Additionally, given negative associations related to online homework, software, and e-textbooks, their inclusion in developmental mathematics courses should be carefully considered and supplementary. This is especially critical given that corequisite courses included in this study reportedly had integrations of online homework and software, and with a 100% requirement for developmental mathematics students to be enrolled in corequisite courses, the integration practices for these two technologies in the corequisite developmental mathematics courses and the connected gatekeeper mathematics courses must be deliberated. When these technologies are integrated, they should be offered in addition to traditional course materials or instructional approaches and incorporate instructor feedback to the students. Although online platforms used for completing homework, engaging with mathematics content, and reading the text may work for some students, these should not serve as replacements to instructor-led instruction or paper-based texts and assignments. Such flexibility will address accessibility issues and the needs of developmental mathematics students.

The final recommendation for practice relates to the larger learning environment outside of developmental mathematics classrooms. Consistent with Texas mandates for professional development of developmental education instructors, training and resources for technology integration must be included. If instructors are to use technology in their classes, they must be able to use it well. Such professional development is critical to the practice of technology use but, most importantly, to contributing to effective teaching of developmental mathematics students and enhancing students' learning.

Although these recommendations may be connected to this study's results, they also are supported in the literature. Natow et al. (2017) discussed using learning management systems, noting challenges with students' and instructors' technology skills being sufficient to interact with web-based content. The authors' recommendation included providing instructors with training on technology, broadly, as well as for specific learning management systems. MacDonald et al. (2002) studied the use of graphing calculators in developmental mathematics courses. Their findings suggested that the use of graphing calculators was beneficial for students under two conditions. First, real-world examples requiring mathematics skills should be used in the problems. Most importantly, students should be instructed using alternatives to graphing calculators, such as with spreadsheets and software-based graphing and function features like those found in Microsoft Excel (MacDonald et al., 2002).

Wladis et al. (2014) found that students had statistically significant higher pass rates when they completed online homework. The important aspect of assigning online homework was that it was supplementary to face-to-face instruction, and it was assigned only to those developmental mathematics students who earned below a 70% on a midterm examination. Spradlin and Ackerman (2010) who, like Wladis et al. (2014) studied online homework for developmental mathematics students, found the students earned higher grades when their online homework was supported by immediate feedback from their instructors. The findings from these two studies support the recommendations for supplementary use of online homework that incorporates instructor feedback.

Related to technology-mediated developmental mathematics courses in which software was used were the findings from studies by Kashyap and Mathew (2017) and Kinney and Robertson (2003). Kashyap and Mathew (2017) reviewed software in developmental mathematics courses used to assign homework and practice problems and compared their performance to students in courses without software use. Their findings indicated the students who completed mathematics problems using the software earned statistically significantly higher grades than those who did not. Of import to this study's institutional setting as well as others is that Kashyap and Mathew focused specifically on software use in corequisite developmental mathematics courses, noting its success. Similarly, Kinney and Robertson (2003) explained that software should support but not replace instruction in developmental mathematics courses.

Conclusion

This dissertation study focused on exploring whether relationships between technology use in developmental mathematics courses and student performance measures, credit status in developmental and passing grades in gatekeeper mathematics courses, existed. The findings indicated statistically significant associations indeed existed in certain circumstances, including for technology use overall and specific technologies—graphing calculators, scientific calculators, online homeworking, learning management systems, software, and e-textbooks—at both course levels to varying degrees. That technology broadly and, especially, particular types of technology were associated with student performance suggests developmental mathematics teaching and learning may benefit and be challenged by technology integration into such courses, proving valuable to or, perhaps, complicating students' learning, and, ultimately, affecting students' progress in passing gatekeeper mathematics courses.

Although there are answers to the two research questions of this study, the associations discovered are only part of the picture. There are complexities to how technology was—and should be—used, the needs of instructors and students, institutional resources, and the policy environment in which technology is mandated by the state that must be considered. Further studies in similar scope would contribute to generating evidence of technology and student performance associations, as could expanded study using different forms of statistical analyses, additional technologies based in the literature, and other performance measures. Practices should focus on expanding professional development and training on the technologies used in developmental mathematics courses for both instructors and students. Further, practices should remain flexible to enhance teaching and learning through technology-enhanced and non-technology-enhanced approaches. Although this study may contribute to informing policy, practice, and research, it is but one step in the direction of filling a literature gap on the effectiveness of technology in developmental mathematics courses and urging the field to move forward in exploring and developing research-based practices for such purposes.

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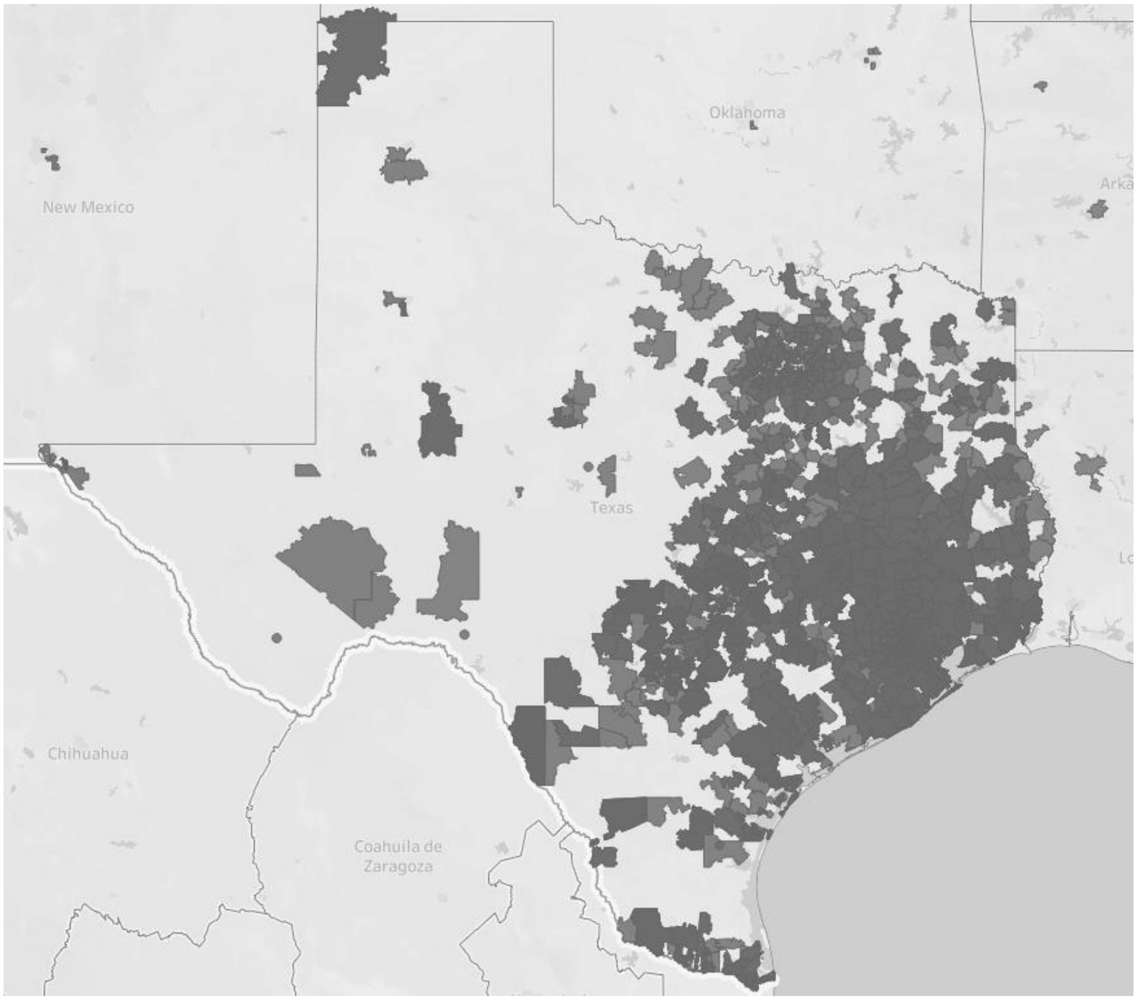
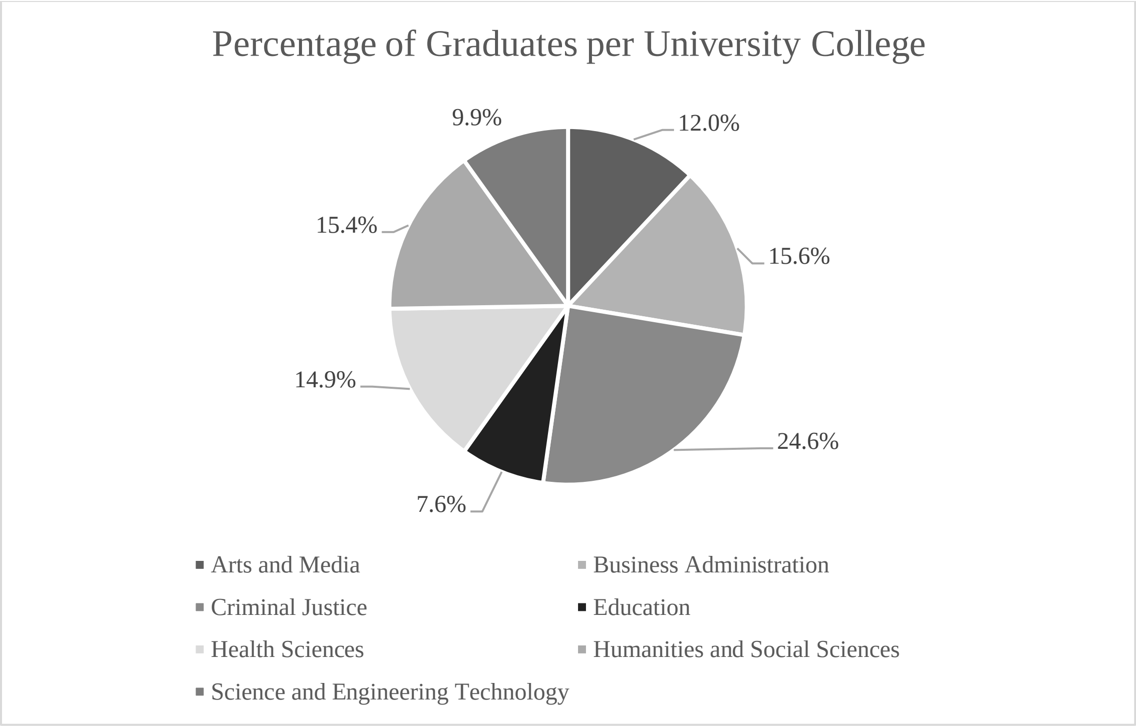
APPENDIX A

Zip Code Density for Students Living in Southeast Texas



APPENDIX B

Proportion of Developmental Mathematics Students Who Graduated from Each University College.



APPENDIX C

Counts and Percentages of Developmental Mathematics Students Who Graduated by University College

College	Graduates	
	N	%
Arts and Media	356	12.0
Business Administration	465	15.6
Criminal Justice	732	24.6
Education	227	7.6
Health Sciences	442	14.9
Humanities and Social Sciences	457	15.4
Science and Engineering Technology	294	9.9

APPENDIX D

Distribution of Letter Grades Earned by Students in Gatekeeper Mathematics Courses

Course	A		B		C		D		F	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
MATH 1314: Pre Calculus Algebra	189	12.1	375	24.0	477	30.5	227	14.5	296	18.9
MATH 1316: Plane Trigonometry	43	11.6	92	24.8	129	34.8	47	12.7	60	16.2
MATH 1324: Mathematics for Managerial Decision Making	128	11.7	277	25.4	351	32.1	211	19.3	125	11.4
MATH 1332: College Mathematics	525	17.7	869	29.2	831	28.0	495	16.7	252	8.5
MATH 1369: Elementary Statistics	107	25.4	100	23.8	110	26.1	62	14.7	42	10.0

(continued)

Course	A		B		C		D		F	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
MATH 1384: Introduction to Foundations of Math I	70	14.6	177	37.0	193	40.3	27	5.6	12	2.5
MATH 1410: Elementary Functions	16	8.0	55	27.6	64	32.2	22	11.1	42	21.1
MATH 1420: Calculus I	13	8.6	35	23.0	57	37.5	20	13.2	27	17.8
PHIL 2352: Introduction to Contemporary Logic	4	13.3	6	20.0	6	20.0	5	16.7	9	30.0
STAT 1369: Elementary Statistics	50	23.8	60	28.6	54	25.7	30	14.3	16	7.6

APPENDIX E

Gatekeeper Mathematics Course Pairs with Statistically Significantly Different GPAs

Gatekeeper Mathematics Course I	Greater or Lesser GPA	Gatekeeper Mathematics Course II	*p*
MATH 1314	<	MATH 1332	< .001
MATH 1314	<	MATH 1369	< .001
MATH 1314	<	MATH 1384	< .001
MATH 1314	<	STAT 1369	< .001
MATH 1316	<	MATH 1332	.001
MATH 1316	<	MATH 1369	.001
MATH 1316	<	MATH 1384	< .001
MATH 1316	<	STAT 1369	.001
MATH 1324	<	MATH 1332	< .001
MATH 1324	<	MATH 1369	< .001
MATH 1324	<	MATH 1384	< .001
MATH 1324	<	STAT 1369	< .001
MATH 1332	<	MATH 1384	.001
MATH 1332	>	MATH 1410	< .001

(continued)

Gatekeeper Mathematics Course I	Greater or Lesser GPA	Gatekeeper Mathematics Course II	*p*
MATH 1332	>	MATH 1420	.001
MATH 1369	>	MATH 1410	< .001
MATH 1369	>	MATH 1420	.001
MATH 1384	>	MATH 1410	< .001
MATH 1384	>	MATH 1420	< .001
MATH 1384	>	PHIL 2352	.01
MATH 1410	<	STAT 1369	< .001
MATH 1420	<	STAT 1369	< .001
PHIL 2352	<	STAT 1369	< .001

Note. All unique course pairs shown. Statistically significant differences were noted where $p < .05$.

APPENDIX F

Chi-Square Results for Developmental and Gatekeeper Mathematics Courses Related to Learning Management Systems

Course	χ^2	p	V
MATH 0112: Intermediate Algebra	2.01	.74	.08
MATH 0331: Developmental Mathematics I	4.50	.34	.06
MATH 0332: Developmental Mathematics II	6.70	.15	.03
MATH 1314: Pre Calculus Algebra	7.83	1.00	.07
MATH 1316: Plane Trigonometry	2.96	.56	.09
MATH 1324: Mathematics for Managerial Decision Making	3.18	.53	.05
MATH 1332: College Mathematics	7.76	.10	.02
MATH 1369: Elementary Statistics	4.16	.39	1.00
MATH 1384: Introduction to Foundations of Math I	4.81	.30	.10
MATH 1410: Elementary Functions	3.76	.35	.15
MATH 1420: Calculus I	5.62	.23	.20

(continued)

Course	χ^2	p	V
PHIL 2352: Introduction to Contemporary Logic	4.26	.28	.44
STAT 1369: Elementary Statistics	1.94	.75	1.00

Note. Fisher’s exact statistic reported for MATH 1316, 1384, 1410, 1420, and PHIL 2352 because expected values were less than five. Degrees of freedom was four (df = 4). Not all developmental mathematics courses included because use of learning management systems was a constant and could not be analyzed using chi-square. Statistically significant associations were noted where $p < .05$; here, none were identified.

APPENDIX G

Chi-Square Results for Developmental and Gatekeeper Mathematics Courses Related to E-textbooks

Course	χ^2	*p*	*V*
MATH 0112: Intermediate Algebra	.59	.90	.04
MATH 0331: Developmental Mathematics I	1.38	.85	.03
MATH 0332: Developmental Mathematics II	11.39	.02	.04
MATH 1314: Pre Calculus Algebra	4.07	.40	.05
MATH 1316: Plane Trigonometry	5.54	.24	.12
MATH 1324: Mathematics for Managerial Decision Making	2.54	.64	.05
MATH 1332: College Mathematics	3.16	.53	.03
MATH 1384: Introduction to Foundations of Math I	4.86	.30	.10

Note. Degrees of freedom was four ($df = 4$). Not all gatekeeper mathematics courses included because use of e-textbooks was a constant and could not be analyzed using chi-square. Statistically significant associations were noted where $p < .05$.

APPENDIX H

Chi-Square Results for Course Pairs of Developmental and Gatekeeper Mathematics Courses Related to Learning Management Systems

Developmental Mathematics Course	Gatekeeper Mathematics Course	χ^2	*p*	*V*
MATH 0112	MATH 1314	2.00	.74	.08
MATH 0331	MATH 1314	4.65	.33	.06
MATH 0331*	MATH 1316	5.42	.21	.36
MATH 0332*	MATH 1316	2.23	.72	.09
MATH 0332	MATH 1324	3.18	.53	.05
MATH 0332	MATH 1332	7.76	.10	.05
MATH 0332	MATH 1369	4.16	.39	.10
MATH 0332*	MATH 1384	4.81	.30	.10
MATH 0332*	MATH 1410	3.76	.35	.15
MATH 0332*	MATH 1420	5.62	.23	.20
MATH 0332*	PHIL 2352	4.26	.28	.44
MATH 0332	STAT 1369	1.94	.75	.10

Note. Fisher's exact statistic reported for course pairs designated with an asterisk (*) because expected values were less than five. Degrees of freedom (*df*) was four. Not all mathematics courses included because use of learning management systems was constant and could not be analyzed. Statistically significant associations were noted where $p < .05$; here, there were none.

APPENDIX I

Chi-Square Results for Course Pairs of Developmental and Gatekeeper Mathematics Courses Related to E-textbooks

Developmental Mathematics Course	Gatekeeper Mathematics Course	χ^2	*p*	*V*
MATH 0112	MATH 1314	.59	.96	.04
MATH 0331	MATH 1314	1.84	.77	.04
MATH 0332	MATH 1316	3.90	.42	.11
MATH 0332	MATH 1324	2.54	.64	.05
MATH 0332	MATH 1332	3.16	.53	.03
MATH 0332	MATH 1384	4.86	.30	.10

Note. Degrees of freedom (*df*) was four. Not all mathematics courses included because use of e-textbooks was constant and could not be analyzed. Statistically significant associations were noted where $p < .05$; here, there were none.

VITA

Angela M. Polczynski

EDUCATION

Doctor of Education (Expected August 2021), Developmental Educational Administration
Sam Houston State University, Huntsville, TX
Dissertation title: Exploring the relationship between technology use and student performance in developmental mathematics

Master of Business Administration (December 2013)
Sam Houston State University, Huntsville, TX

Bachelor of Business Administration (August 2008), General Business Studies
Sam Houston State University, Huntsville, TX

PROFESSIONAL EXPERIENCE

Assessment Director, Quality Enhancement Plan ("Healthcare Policy for Health Professionals"), The University of Texas Health Science Center at Houston (UTHealth), Houston, TX
April 2020 – present

Senior Coordinator, Special Programs, McGovern Center for Humanities and Ethics, UTHealth, Houston, TX
August 2015 – present

Coordinator, Special Programs, McGovern Center for Humanities and Ethics, UTHealth, Houston, TX
August 2009 – August 2015

Full-Service Department Project Manager and Research Analyst, Creative Consumer Research, Stafford, TX
July 2006 – April 2009

Data Processor and Programmer, Creative Consumer Research, Stafford, TX
May 2005 – July 2006

Market Research Support Staff, Creative Consumer Research, Stafford, TX
June 1999 – April 2005

PUBLICATIONS

Polczynski, A. M., Rozmus, C. L., & Carlin, N. (2019). Beyond silos: An interprofessional, campus-wide ethics education program. *Nursing Ethics*, *26*(7-8), 2314-2324. https://doi.org/10.1177%2F0969733019832948

Rozmus, C. L., Carlin, N., Polczynski, A., Spike, J., Cole, T., & Buday, R. (2015). The Brewsters: A new resource for interprofessional education. *Nursing Ethics*, *22*(7), 815-826. https://doi.org/10.1177%2F0969733014547974

Carlin, N., Flaitz, C., & Polczynski, A. (2013). Interprofessional ethics: An innovative active-learning experience for health professional students. *Journal of Dental Education*, *77*(2), 224.

CONFERENCE PRESENTATIONS

Rozmus, C. L., Carlin, N., Polczynski, A., & Frazier, L. (2017, July). *Beyond silos: An interprofessional, campus-wide ethics education program* [Paper presentation]. International Nursing Research Congress, Dublin, Ireland.

Polczynski, A. (2017, March). *A road map for applying culturally responsive teaching in the health humanities* [Poster session]. Health Humanities Consortium, Houston, TX.

Polczynski, A. (2016, February). *Exploring the relationships between developmental program characteristics and student performance in community colleges in Texas* [Paper presentation]. Southwest Educational Research Association, New Orleans, LA.

Carlin, N., Flaitz, C., & Polczynski, A. (2013, March). *Interprofessional ethics: An innovative active-learning experience for health professional students* [Poster session]. American Dental Education Association, Seattle, WA.

Carlin, N., Seifert, W., Polczynski, A., Spike, J., & Cole, T. (2012, June). *The Brewsters: A new resource for interprofessional ethics education for health professional schools* [Paper presentation]. International Association of Medical Science Educators, Portland, OR.

AWARDS AND GRANTS

Wellness Grant for Arts and Resilience Program, UTHealth, 2021-2022, $5,000
STAR Award for Ten Years of Service, UTHealth, 2019-2020
Wellness Grant for Arts and Resilience Program, UTHealth, 2018-2020, $5,000
Wellness Grant for Arts and Resilience Program, UTHealth, 2017-2018, $5,000
Graduate Student Travel Grant, Sam Houston State University, 2016, $1,000
STAR Award for Five Years of Service, UTHealth, 2014-2015
Scholarship in Educational Leadership, Sam Houston State University, 2014-2016

PROFESSIONAL MEMBERSHIPS

American Educational Research Association
Kappa Delta Pi
National Organization for Student Success
Southwest Educational Research Association
Textbook & Academic Authors Association