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Developing Technology Applications for Improving the Problem-Solving Skills of Middle School Students with Learning Disabilities

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DEVELOPING TECHNOLOGY APPLICATIONS FOR IMPROVING THE
PROBLEM-SOLVING SKILLS OF MIDDLE SCHOOL
STUDENTS WITH LEARNING DISABILITIES

DISSERTATION

A dissertation submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in the College of Education at the University of Kentucky

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2017

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ABSTRACT OF DISSERTATION

DEVELOPING TECHNOLOGY APPLICATIONS FOR IMPROVING THE PROBLEM-SOLVING SKILLS OF MIDDLE SCHOOL STUDENTS WITH LEARNING DISABILITIES

The achievement gap in mathematics education continues to be a concern in the United States. Students with disabilities (SWD) are often excluded from the general education curriculum or the least restrictive environment due to their low performance in mathematics and disability-related deficits. Legislative and professional reports have addressed the needs of SWD by promoting evidence-based math interventions using instructional technology. However, the focus of many math interventions with instructional technology has been limited to basic facts instruction or drill-and-practice routines. In this study, I developed a curriculum-based technology tool called Anchored Instruction with Technology Applications (AITA) based on pedagogical concepts of Enhanced Anchored Instruction (EAI). For more than a decade, research has shown EAI to be effective in improving the math achievement of SWD. EAI is based on situated cognition learning theory and combines multimedia-based instruction with hands-on problems in real world contexts. AITA integrates technology applications such as 3D printers with EAI curriculum for improving problem-solving skills of SWD. The study examined differential effects of AITA in resource rooms and inclusive classrooms. Results showed significant improvement in favor of AITA for SWD in both problem-solving and computation performance.

KEYWORDS: Enhanced Anchored Instruction, Instructional Technology, Math Intervention, Problem Solving, Students with Disabilities in Mathematics

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This dissertation is dedicated to my beloved parents, InSoo and SunHee,
and brother, Youn-Seung.

이 논문을 사랑하는 나의 부모님과 동생에게 바칩니다.

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CHAPTER 1. INTRODUCTION

Introduction to Problem

The quality of math education has been a longstanding concern in the United States. After the development of the atomic bomb in the 1940's, Steelman (1947) addressed the need to invest in basic math and science and to develop secondary school math programs that would produce greater number of highly trained engineers and scientists for the nation's future. Later, the Soviet's launch of Sputnik in the 1950's caused math educators and researchers to initiate math education reform movement with the extensive federal funding to compete internationally (Kilpatrick, 1992). However, not much attention had been paid to the fact that many American students struggle with low achievement in math education until the National Commission on Excellence in Education published *A Nation at Risk* (U.S. Department of Education, 1983). The authors pointed out several indicators of the risk from the mediocracy in math education across the nation. They stated that "... only one-third [of 17-year-old] can solve a mathematics problem requiring several steps" (p. 9) and many American students did not possess the higher order thinking math skills as expected.

Several attempts have been made to improve math education in the United States. For example, the National Council of Teachers of Mathematics (NCTM) has undertaken reform efforts aimed at improving math performance for American students. In their publications, *An Agenda for Action* (1980) and the *Curriculum and Evaluation Standards* (1989), for example, NTCM developed math standards focusing on instructional and curricular emphases to ensure that students would develop strong math skills for a competent workforce and informed society (NCTM, 1989). Although NCTM's efforts to

restructure math instruction and curriculum seemed appealing to math education in general and promising for all students, special education professionals thought that NCTM's standard-based approach did not consider students with disabilities (SWD) and, which in turn, caused critical issues such as the inequities and low achievement among SWD (Hofmeister, 1993; Hutchinson, 1993b; Mercer, Harris, & Miller, 1993; Rivera, 1993, 1997).

In 2001, as a part of the efforts to resolve achievement gap issues, the *No Child Left Behind Act* ([NCLB], P.L. 107-110) was authorized to ensure equitable educational opportunity for every student, including SWD. One of the NCLB legislation highlights was improving “student academic achievement through the use of technology in schools” (U.S. Department of Education, 2002, p. 85) to bring all students to grade level in both reading and math by 2014. However, despite of the legislative efforts with NCLB, SWD continued to perform lower than their peers without disabilities, and continuous achievement gaps between SWD and students without disabilities (SWOD) were evident (National Center for Education Statistics [NCES], 2015). The new legislation, *Every Student Succeeds Act* ([ESSA], P.L. 114-95), was passed to replace NCLB in 2015 and to resolve the ongoing low achievement issues. The ESSA mandated schools to develop an evidence-based plan to help low-achieving subgroups of students who were falling behind, such as minority students or SWD (U.S. Department of Education, 2016). One major difference of the ESSA legislation from NCLB is its emphasis on the “effective” use of technology to improve the academic achievement and growth for all students including SWD as mentioned as following:

Technology can expand growth opportunities for all students while affording historically disadvantaged students greater equity of access to high-quality learning materials, field experts, personalized learning, and tools for planning for future education. Such opportunities can also support increased capacity for educators to create blended learning opportunities for their students, rethinking when, where, and how students complete different components of a learning experience. However, for technology to be truly transformative, educators need to have the knowledge and skills to take full advantage of technology-rich learning environments (U.S. Department of Education, 2016, pp. 31-32).

This indicates that educators not only need to seek evidence-based technology tools, but they also need to have technology-related knowledge and skills in order to use technology applications “effectively” in the instructional settings.

One of the research-based instructional approaches using technology is called Enhanced Anchored Instruction (EAI), which is multimedia-based instruction to improve the problem-solving skills of SWD and SWOD (Bottge, Heinrich, Chan, & Serlin, 2001). For more than a decade, Bottge and colleagues have studied the effectiveness of EAI for improving math achievement of SWD (Bottge, 2001b; Bottge & Hasselbring, 1993; Bottge et al., 2001; Bottge, Heinrichs, Mehta, & Hung, 2002; Bottge, Ma, Gassaway, Toland, Butler, & Cho, 2014; Bottge, Toland, Gassaway, Butler, Choo, Griffen, & Ma, 2015).

Another technology-based approach for improving the math skills of students uses 3D printers. Over the past several years, 3D printing technology has been a part of school curriculum including math education and continues to have a significant impact on

students' academic achievement and their everyday lives as well (Lacey, 2010; Murray, 2013; Sheridan, Halverson, Litts, Brahms, Jacobs-Priebe, & Owens, 2014; Sheridan, Clark, & Williams, 2013). When these technology-based instructional approaches are “carefully designed and thoughtfully applied, technology can accelerate, amplify, and expand the impact of effective practice that support student learning, increase community engagement, foster safe and healthy environment, and enable well-rounded educational opportunities” (U.S. Department of Education, 2016, p. 31).

Background of the Study

Learning Disabilities in Mathematics

The recent National Assessment of Educational Progress reports indicated that continuous achievement gaps for SWD and other subgroup populations have been evident and their mathematics performance in the state assessments has been persistently low, while most students in the United States have made progress of mathematics achievement over the years (NCES, 2011, 2012, 2013, 2015). NCES's latest report in 2015 revealed that 45% of fourth-grade, 68% of eighth-grade, and 77% of twelfth-grade SWD perform below *Basic* level in mathematics compared to only 14% of fourth-grade, 23% of eighth-grade, and 34% of twelfth-grade low-performing SWOD. In addition, a technical report of National Center on Educational Outcomes (2012) showed that low-performing middle school SWD more likely stay in the low-performing group when they attend high school than low-performing SWOD.

In addition to the underachievement issue in national assessments, another concern is the growing number of students with learning disabilities in mathematics (SMD). While 6.7 million or 14% of total school age children across the United States

receive special education services (NCES, 2015), 4.9% of the total population are affected by specific learning disabilities and often experience math-related difficulties (NCES, 2012). The NCES also indicated that the number of students with learning disabilities has grown more than 300% since 1976, and there might be an overrepresentation of minorities in this category (Barbarese, Katusic, Colligan, Weaver, & Jacobsen, 2005; Fuchs & Fuchs, 2002; Fuchs, Fuchs, & Hollenbeck, 2007; Geary, 2004; Gross-Tsur, Manor, & Shalev, 1996; Mazzocco, 2005; Mazzocco & Devlin, 2008).

SMD have more likely struggled in a traditional classroom than SWOD due to their difficulties to participate in a typical classroom environment, and the underachievement problem of SMD has been persistently consistent compared to SWOD (Hasselbring & Glaser, 2000). According to the Individuals with Disabilities Education Improvement Act of 2004 ([IDEA], P.L. 108-446), SMD often struggle with mathematics calculation and mathematics problem solving. Researchers have examined characteristics of SMD and found that those students tend to have working memory deficits (Fuchs & Fuchs, 2002; Geary, 2004; Gonzalez & Espinel, 2002), fact retrieval and computation problems (Fuchs & Fuchs, 2002; Gonzalez & Espinel, 2002), difficulties in solving multi-step problems (Bryant, Bryant, & Hammill, 2000; Fuchs & Fuchs, 2002), and lack of mathematical vocabularies (Bryant et al., 2000).

Math Interventions

Researchers have conducted meta-analyses of mathematics interventions to identify the most effective for SMD (Gersten, Chardk, Jayanthi, Baker, Morphy, & Flojo, 2009; Kroesbergen & Van Luit, 2003; Swanson & Hoskyn, 1998; Swanson & Sachse-Lee, 2000). The results from four meta-analyses indicated that direct or explicit

instruction (e.g., teaching step-by-step procedures) was one of the most effective mathematics interventions from studies conducted with SMD. However, some researchers (e.g., Woodward, 2004; Woodward, Baxter, & Robinson, 1999) argued that direct instruction can often cause retention problems of SMD. Other investigators (e.g., Hasselbring, Lott, & Zydney, 2006) suggested that mathematical knowledge taught by procedural instruction is accessed only in a restricted set of contexts, and such knowledge cannot be used in real-world contexts (i.e., inert knowledge).

To resolve retention problems and the inert knowledge issue, the Cognition and Technology Group at Vanderbilt (CTGV) developed an instructional strategy called Anchored Instruction (AI). AI immerses students in complex problem situations with video-based stories and then requires students to sift through embedded relevant information to formulate and solve problems (CTGV, 1990, 1992). CTGV proposed that learning mathematics in the context of the video story provides learning opportunities for students to connect their math skills to real-world situations. However, SMD especially those who significantly underperform, experienced another issue with AI approach. Bottge and colleagues found that low-achieving students without proper foundation skills were not engaged in complexed problem-solving situation. They copied other students' work or often avoided tasks (Bottge et al., 2002). Bottge's research has continued to improve both basic computational skills and problem-solving skills specifically for SMD as an "enhanced" version of AI (Bottge, 1999, 2001b; Bottge et al., 2002).

Educational Technology in Special Education

The use of technology to help SWD has been an important area of research and practice in special education since the Technology Related Assistance for Individuals

with Disabilities Act (Tech Act) was first passed in 1988 (P.L. 100-407) and reauthorized in 1994 (Blackhurst, 2005a; Bryant & Seay, 1998; Roper, 2006). In addition, the Assistive Technology Act of 1998 (P.L. 105-394) defined and extended the use of technology for SWD (U.S. Department of Education, 2006), and the IDEA mandated that every Individualized Education Program should consider whether the child needs assistive technology devices and services in order to access the general curriculum within the least restrictive environment. A number of researchers suggested that the integration of technology has been effective in providing SWD with new opportunities to engage in important classroom activities (Blackhurst, 2005b; Bryant, Bryant, & Raskind, 1998; Hasselbring & Glaser, 2000; Lewis, 1998, 2000; Okolo, 1990; Okolo & Diedrich, 2014).

Technology for SWD is often referred to as assistive technology, and assistive technology is defined as “any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain or improve functional capabilities of individuals with disabilities” (U.S. Department of Education, 2006, p. 6). However, researchers have shown that for SWD, technology has been used not only as personal assistive devices (assistive technology), but also an extension of instructional aids (computer-assisted instruction), information management devices (computer-managed instruction), instructional delivery tools, other technology tools, or combination of assistive and instructional technology (Hofmeister, 1984; Lewis, 1998, 2000; Roper, 2006).

Blackhurst (2005b) stated that technology in special education can be categorized into six different types: technology of teaching (i.e., teaching strategies); instructional technology (see Presidential Commission on Instructional Technology, 1970); assistive

technology (see U.S. Department of Education, 2006); medical technology (that allows people to stay outside of hospital or other medical settings); technology productivity (that enables people to work more effectively and efficiently); and information technology (that provides access to knowledge and resources on a wide range of topics). Such educational technology has been beneficial for SWD in various areas not limited to functional capabilities of individuals (Blackhurst, 2005b). Educational technology is defined as “the study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources” (Association for Educational Communications and Technology, 2007, p. 1), and technology-based educational materials deliver learning content and support the learning process (Cheung & Slavin, 2013).

Statement of Problem

For several decades, improving students’ problem-solving skills in math has been emphasized in math education research community and government-based reports. In *An Agenda for Action*, NCTM (1980) proposed that schools should organize math curricula around problem solving. NCTM has continuously led math educators to create learning environment in which students apply problem-solving strategies across all mathematical content areas and has encouraged researchers to examine effective ways to develop problem-solving skills for students (NCTM, 1989, 1991, 2000). Especially, in the *Principles and Standards for School Mathematics*, NCTM (2000) emphasized the importance of conceptual understanding and mathematical problem-solving approach. The council stated that problem-solving skills should be a top priority in math instruction, and problem-solving approaches should be used to teach school math. In addition,

government reports such as *Goals 2000: Educate America Act* (U.S. Department of Education, 1994) and *What Work Requires of Schools: A SCANS Report for America 2000* (U.S. Department of Labor, 1991) supported the importance of problem solving in mathematics as well.

In general, problem solving is “a complex cognitive skill that characterizes one of the most intelligent human activities” (Chi & Glaser, 1985, p. 227). More specifically, problem-solving ability refers to an individual’s capacity to use cognitive process where the solution is not immediately obvious, and prior knowledge is required to find a solution (Hudson & Miller, 2006; Schoenfeld, 1985; Swanson & Sachs-Lee, 2000). Since Polya (1945) introduced four-step heuristics (e.g., understanding question, devising a plan, carrying out the plan, and looking back and checking), problem-solving success has been considered as a primary outcome variable in mathematics education, and number of studies have been conducted to support for problem-solving instructions across the nation (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010; National Mathematics Advisory Panel [NMAP], 2008; NCTM, 2002).

Despite of the importance of problem solving, many researchers have shown that problem solving is one of the most difficult mathematical skills that secondary school students experience whether or not they have disabilities (Jitendra, DiPipi, & Perron-Jones, 2002; Montague, Enders, & Dietz, 2011; Xin, Jitendra, Deatline-Buchman, 2005). For SWD, difficulties in problem solving are more evident for SWD. For example, Geary (1994, 2000, 2004) stated that computational (arithmetic) and problem-solving (e.g., word problems) deficits are consistent among SWD. Moreover, Bryant and colleagues

(2000) argued that word problem solving is the most problematic area for SWD. From their elementary school years, SWD experience difficulties in working memory, fact retrieval, problem conceptualization, and problem solving (Jordan & Hanich, 2000; Krawec, 2014). When SWD attend in middle school, they continue struggling with problem solving, because they are less likely to use representational strategies or metacognitive approaches when solving mathematics problems (Montague, Applegate, & Marquard, 1993). In addition to the problem-solving deficits that SWD often have, many teachers still spend significantly more time on computational and procedural skills than reasoning and problem-solving skills (Fuchs & Fuchs, 2002; National Research Council, 2001). For example, some studies suggested that only 19% of teachers engage their students in any kind of problem-solving activities (Hiebert & Stigler, 2000).

One suggested instructional approach for improving students' problem-solving skills involves using video anchors with hands-on projects such as Enhanced Anchored Instruction (EAI). Studies from Bottge and colleagues showed that EAI has effectively improved problem solving skills of SWD in various grade levels and instructional settings (Bottge et al., 2002; Bottge, Rueda, LaRoque, Serlin, & Kwon, 2007; Bottge, Ma, Gassaway, Toland et al., 2014; Bottge et al., 2015). Technology is another essential tool in teaching and learning math that can improve students' problem-solving skills (NCTM, 2000), yet technology by itself does not guarantee automatic improvement of student learning (Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000). The essence of the problem is, then, how can technology be integrated into the EAI curriculum and become an important element of students' education to enhance problem-solving skills of SWD?

Purpose of the Study

The purpose of the study is to develop a curriculum-based technology tool, called Anchored Instruction with Technology Tools (AITA), for improving problem-solving skills of middle school SWD and SWOD. AITA is a collection of technology tools that extends the applications of EAI, which Bottge and his colleagues have shown effective. It is important to examine the link between the EAI curriculum and the use of technology applications in the actual instructional setting when testing its effectiveness. Thus, this study compared the differential effects of AITA implementation on student math achievement compared to Business as Usual (BAU) instruction and to the current version of EAI. Considering SWD receive math instruction in either resource room or inclusive classroom, this study examined the impact of instructional setting and its interaction effect with AITA as well. The study further investigated the effects of participating students' variables including disability status.

Research Questions

The overall research questions that guided this study were:

1. What are the differential effects of three instructional conditions (AITA group, EAI group, BAU group) on the problem-solving skills of middle school SWD?
2. How do learning theories help to explain the findings in research question 1?

The results of this study determined the main effect of the AITA curriculum on middle school students' math achievement tests compared to the BAU curriculum and/or the EAI curriculum. In addition, the main effect of classroom factor, such as instructional setting between resource room and inclusive classroom on middle school students' math

achievement tests was investigated. The study also compared the interaction effect between treatment conditions (AITA, EAI, BAU) and the classroom factor (instructional setting). Finally, the study examined the impacts of student characteristics, such as age, ethnicity, gender, and disability status on student achievement for math problem-solving skills.

Significance of the Study

Over the past several decades, math education in the United States has been significantly grown. Math education reform efforts have been evident by government reports, research and professional communities, and practicing educators (Dossey, McCrone, & Halvorsen, 2016; NCTM, 2016; Wu, 1997). However, the field of special education tends to conduct more research on reading intervention than math intervention. In fact, the focus of math instruction in special education settings has been limited to basic facts or simple computation and using drill and practice for brief intervention (Fuchs, Compton, Fuchs, Paulsen, Bryant, & Hamlett, 2005). The contributions of this study would be of interest to researchers in math education, special education, and practicing educators, particularly those who seek effective instructional technology for improving math skills of SWD. The study also proposes to develop an evidence-based math intervention to improve student outcomes with effective instructional technology, as mandated by the ESSA, for schools where student subgroups including SWD are struggling with low achievement issues.

Middle school mathematics has been and continues to be a concern to educators and researchers in mathematics and special education (Bouck, Kulkarni, & Johnson, 2011), and problem solving is the most challenging but important area of the mathematics

curriculum for many students, including SWD throughout their school ages (Bryant et al., 2000). Due to their underachievement in math and other disability-related deficits, SWD have been excluded from general education settings and have not made progress through the general education curriculum; yet IDEA mandated the right of SWD to have access to the general education curriculum in the least restrictive environment. Many researchers have attempted to identify the most effective instructional approach for SWD such as EAI and through the use of instructional technology tools, but up to date, little research has been attempted to blend both approaches to improve problem-solving skills for middle school SWD.

Theoretical and Conceptual Framework

The main theoretical framework for this study is Bottge's (2001a) the *Key Model of Problem Solving* (p. 104). Based on historical learning theories including Whitehead (1929), Dewey (1959), Wertheimer (1959), and Bruner (1960), Bottge developed important conditions for successful teaching and learning. As illustrated in Figure 1, Bottge proposed that each component of successful learning – (a) engagement, (b) foundations, (c) intuitions, (d) transfer, (e) cultural supports, and (f) student-specific – can be achieved by each aspect of instruction – (a) meaningful, (b) explicit, (c) informal, (d) (de)situational, (e) social, and (f) teacher-specific teaching (respectively). The model suggests that if any of the instructional components is missing or does not support any learning components, student learning would be limited.

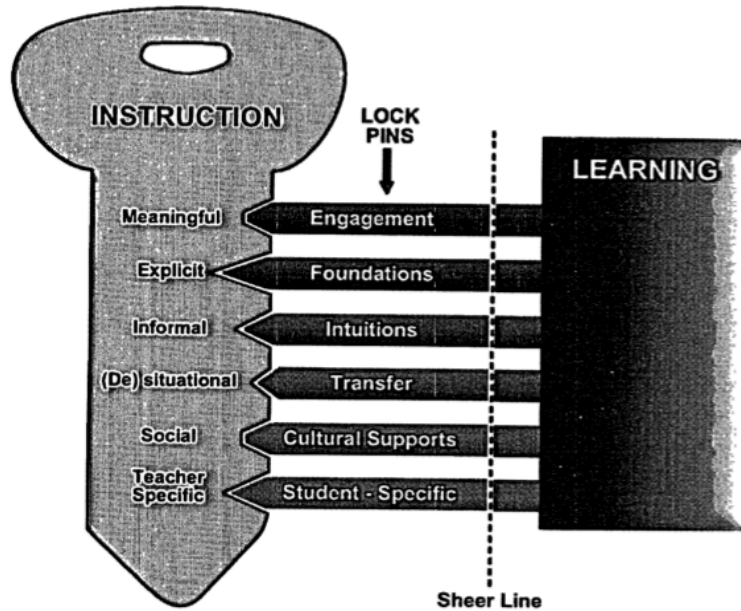


Figure 1. The Key Model of Problem Solving. Adapted From “Reconceptualizing Mathematics Problem-Solving for Low-Achieving Students” by B. Bottge, 2001, *Remedial and Special Educations*, 22(2), p. 104.

Another conceptual framework for the present study is the *Technological Pedagogical Content Knowledge Framework* (Koehler & Mishra, 2009; Koehler, Mishra, Kereluik, Shin, & Graham, 2014; Mishra & Koehler, 2006). Based on Schulman’s (1986, 1987) notion of relationship between content and pedagogy, Mishra and Koehler (2006) proposed the importance of the connections between technology, pedagogy, and content knowledge. As illustrated in Figure 2, each component among technology, pedagogy, and content knowledge is paired with another knowledge creating new domains such as pedagogical content knowledge, technological content knowledge, technological pedagogical knowledge, and all three taken together as technological pedagogical content knowledge. As Mishra and Koehler (2006) argued that “good teaching requires an understanding of how technology relates to the pedagogy and content” (p. 1026), the

effective use of educational technology must be considered within the context of the subject matter (content) and the means of teaching it (pedagogy).

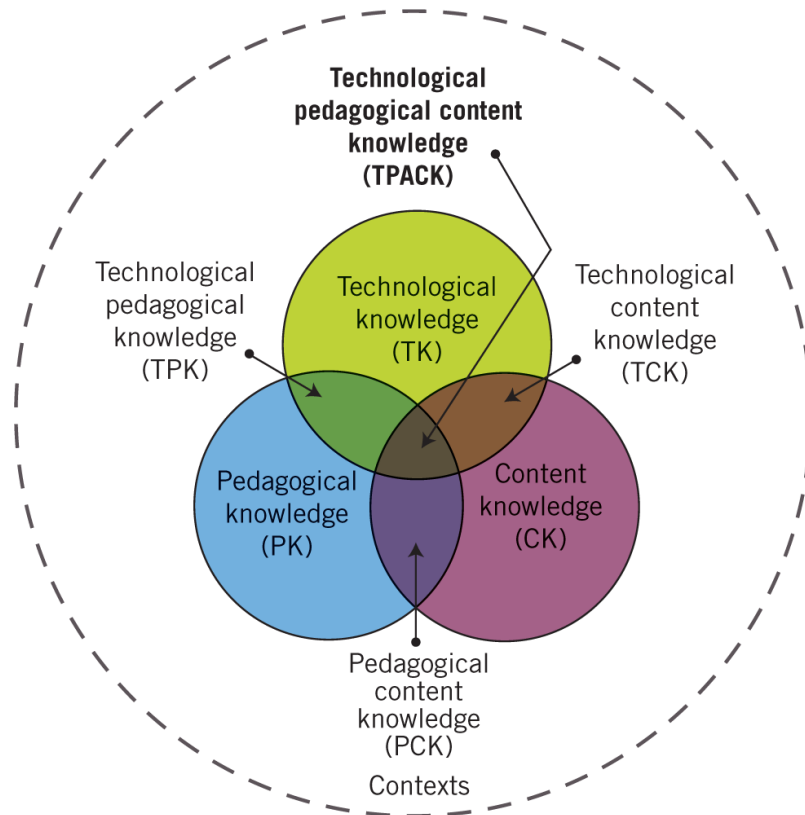


Figure 2. The Technological Pedagogical Content Knowledge Framework. Adapted from “The technological pedagogical content knowledge framework” by M.J. Koehler, P. Mishra, K. Kereluik, T. S. Shin, & C. R. Graham, 2014, *Handbook of Research on Educational Communications and Technology*, p. 103.

Nature of the Study

The current study used a variation of quasi-experimental design based on factorial design and multiple treatments and controls with pretest. The factorial design makes it possible for the researcher to examine the main effects of three different instructional conditions (AITA, EAI, BAU) and two different instructional settings (resource room, inclusive classroom) on students’ math achievement tests as well as the interaction effect between two variables (Shadish, Cook, & Campbell, 2002). Another design used in the

study was multiple treatments and controls with pretest, which would ensure that multiple treatment conditions are equally effective (or ineffective) and would minimize internal validity issues that multi-group designs may cause (Shadish et al., 2002). The hybrid research design for this study can be diagramed in this way:

NR	O ₁₂₃₄	X _{A1}	O ₁₂₃₄
NR	O ₁₂₃₄	X _{A2}	O ₁₂₃₄
NR	O ₁₂₃₄	X _{B1}	O ₁₂₃₄
NR	O ₁₂₃₄	X _{B2}	O ₁₂₃₄
NR	O ₁₂₃₄	C ₁	O ₁₂₃₄
NR	O ₁₂₃₄	C ₂	O ₁₂₃₄

where NR represents non-randomized group assignment. The first O (observation, measurement) represents pretests, and the second O represents posttest with the four subscripts corresponding to the four different measures. For experimental groups, X_{A1} represents AITA implemented in resource room, X_{A2} represents AITA implemented in inclusive classroom, X_{B1} represents EAI implemented in resource room, and X_{B2} represents EAI implemented in inclusive classroom. The control groups are represented as C₁ and C₂ with the subscript number corresponding to resource room and inclusive classroom, respectively.

Definition of Terms

The following terms are used throughout the study:

BAU. BAU refers to the control group instruction aligned with Common Core State Standards for Mathematics ([CCSS-M], National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) and modified by districts, schools, or individual teachers.

EAI. EAI refers to the project-based instruction with contextualized problems delivered through multimedia tools. For this study, the instructional units of EAI conditions include *Fraction of the Cost* (FOC) and *Hovercraft* (HOV). Two instructional units focus on improving problem-solving skills based on the concepts of Ratios and Proportional Relationships, Number System, and Geometry. Participating teachers received training for EAI curriculum implementation, had access to daily lesson plans, and were supplied with all instructional materials.

AITA. AITA refers to the curriculum-based technology tool based on the EAI instructional units. The AITA condition includes FOC, one of the EAI's instructional units, to ensure students' foundational skills for the following two units of *Flatland* (FL) and *3D-Hovercraft* (3D-HC), which consist of video story and the use of computer-aided drawing (CAD) software and 3D printers. Participating teachers received training for AITA curriculum implementation with daily lesson plans and all instructional materials.

SWD. SWD refers to students who have any diagnosed disabilities. SWD receive special education services in resource rooms and/or inclusive classrooms indicated by their Individualized Education Plans.

SWOD. SWOD refers to students without disabilities including those who receive special education instructions in inclusive classrooms with SWD.

SMD. SMD refers to students with learning disabilities in mathematics or math disabilities. This is not limited to specific learning disabilities in general but includes particularly those who struggle in learning mathematics with low achievement.

Resource Room. Resource room refers to a self-contained classroom where a single special education teacher teaches. Only SWD are placed in resource room to receive math instruction with Individualized Education Programs.

Inclusive Classroom. Inclusive classroom refers to a general math classroom where one math teacher and one special education teacher teach together. In inclusive classroom, both SWD and SWOD are placed to receive math instruction.

Assumptions

The following assumptions were made as part of the present study:

1. Students and teachers are equivalent across the groups.
2. All students respond to the math achievement tests, and the results of pretests and posttests accurately show the level of their math performance.
3. Students' problem-solving skills can be measured by the Problem-Solving test, Spatial Thinking Ability Test, and The Iowa Tests of Basic Skills.
4. All teachers deliver math instructions effectively, and teachers in EAI and AITA conditions effectively teach all units of each curriculum.
5. Teachers in AITA conditions effectively use technology tools such as 3D printers and CAD software.
6. All three treatment conditions cover the same math curriculum aligned with CCSS-M (2010).

CHAPTER 2. LITERATURE REVIEW

Instructional Technology for Students with Disabilities

Students with disabilities (SWD) more likely play passive roles in academic settings, and their progress is substantially slower than students without disabilities (SWOD) unless there is additional support in their class to mediate the instruction (Lewis, 2005; Woodward, 2004). Researchers revealed that instructional technology enables SWD to compensate in areas where they lack the necessary learning skills and helps them improve certain skill deficiencies (Cavalier, Ferretti, & Okolo, 1994; Garner & Campbell, 1987; Hasselbring & Bausch, 2005; Lewis, 1998). In addition, numerous studies have shown that technology has a profound impact on specifically improving academic performance, such as literacy, communication, and math skills (Bouck & Flanagan, 2009; Bryant et al., 1998; Hasselbring & Glaser, 2000; Hasselbring et al., 2006; Lewis, 1998, 2000; Okolo & Diedrich, 2014; Roper, 2006; Woodward, 2004). While many technology applications used for SWD include computer-based technology in teaching and learning, traditional instructional materials, such as textbook, manipulatives, or calculators, have been used as instructional aids to help student learning or as teaching tools to carry out academic contents (Kidwell, Ackerberg-Hastings, & Roberts, 2008). Such materials can meet students' individual needs when carefully evaluated and systematically designed to teach SWD (Blackhurst, 2005a; Kelly, Gersten, & Carnine, 1990).

Textbooks

Textbooks have been one of the primary teaching tools in U.S. education history (Anderson & Armbruster, 1984; Kidwell et al., 2008; Lovitt & Horton, 1994). Textbooks

also have been an integral part of typical classroom instruction, as they consist of teaching goals and objectives, sequentially planned materials, and learning activities (Silbert, Carnine, & Stein, 1981). However, inadequate use of textbook caused generalization and maintenance problems among SWD (Lambert, 1996). Lambert argued that textbooks should be modified to meet individual needs of SWD. When textbooks are modified or customized to improve academic performance of SWD, they can serve as an instructional technology tool.

Bergerud, Lovitt, and Horton (1988), for example, conducted a study to examine the effect of textbook adaptations of high school SWD on retention skills in science class. Two different textbook adaptation methods were used, such as graphics and study guides, and the adaptations were compared to traditional passage-based textbooks. The results indicated that addition of graphics was the most effective on student science performance on a retention measure among three types of textbooks. However, no difference was found between the use of study guides and traditional passage-based textbooks. This study supported the proper use of educational technology with existing resources because textbooks were modified to “increase, maintain, or improve” science skills of SWD.

Manipulatives

SWD often struggle in textbook-oriented teaching due to their deficits in language or reading skills (Mastropieri & Scruggs, 1994; McCarty, 2005). Although textbooks convey academic contents and include learning activities, such activities are paper-and-pencil tasks, and SWD are rarely encouraged to apply what they have learned into real-world problems. Lambert (1996) argued that manipulatives can be used to teach a variety of academic concepts by providing meaningful opportunities and having students actively

involved in learning process. According to Maccini and Gagnon (2000), manipulatives are hands-on, concrete materials to represent a variety of academic concepts.

Studies have shown that using manipulatives improve the mathematics skills of SWD (Cass, Cates, Smith, & Jackson, 2003; Funkhouser, 1995; Jordan, Miller, & Mercer, 1998). For example, Cass and colleagues (2003) conducted a single-subject study to examine the effect on acquisition, maintenance, and generalization of geometry skills among high school SWD. In conjunction with teaching strategies (modeling, guided practice, and independent practice), three manipulatives (geoboards, rubber bands, and measuring tape) were employed to improve problem-solving skills in finding area and perimeter. The results indicated that the manipulative-based instruction resulted in the rapid acquisition and maintenance of the geometry problem-solving skills. In addition, the participating students demonstrated their ability to transfer the academic skills to paper-and-pencil-based tasks. This study not only supported findings of previous studies, but it also showed that hands-on items could serve as technology tools to “increase, maintain, or improve” mathematical skills of SWD.

Calculators

After Title I of the Elementary and Secondary Education Act of 1965 provided special funds for students from low-income families, the use of calculators has been common in mathematics classrooms for SWD (Kidwell et al., 2008). Especially, calculators are one of the most common mathematical accommodations written on Individual Education Plans in order for SWD to access grade level mathematical contents (Bouck & Yadav, 2008; Maccini & Gagnon, 2000; Thurlow, Lazarus, Thompson, & Morris, 2005; Shaftel, Belton-Kocher, Glasnapp, & Poggio, 2003). However, some

educators and researchers in mathematics argued that the use of calculator should be limited to complex problems (Kauffman, McGee, & Brigham, 2004), or the impact of calculators on SWD would not be clearly significant (Fuchs, Fuchs, Eaton, Hamlet, & Karns, 2000; Shaftel et al., 2003).

Despite criticism of some researchers, calculators have played a role in enhancing mathematics performance among SWD. Bouck and Bouck (2008) examined the effects on four-function calculators as an accommodation on a mathematics assessment for sixth grade SWD. Another study conducted by Bouck and Yadav (2008) investigated the effectiveness of graphing calculators on open-ended, problem-solving assessments for SWD. Results from both studies showed that the use of calculators was beneficial for SWD in increasing the accuracy of math tests and by reducing computational errors. However, Bouck and Yadav concluded that calculators could not enhance student conceptual understanding that many SWD lack. This implies that some technology applications have limitations, and technology by itself does not guarantee improvement of student learning for certain knowledge.

Computer Applications

According to Hasselbring and Glaser (2000), the use of computers became pervasive and more common in classrooms, and many students have benefited from the integration of computer-based technologies into regular classrooms. Educators and researchers in special education have also attempted to find ways in which computer applications are beneficial for SWD (Lewis, 2005). Examples include word processors, computer-assisted instruction (CAI), and the use of video or embedded multimedia (Hasselbring & Glaser, 2000; Hofmeister, 1984; Lewis, 2000, 2005; Roper, 2006). Those

computer-based applications have not only enhanced academic performances of SWD in primary and secondary education settings (Bouck & Flanagan, 2009; Hasselbring & Bausch, 2005; Hetzroni & Shrieber, 2004), but educational technology has been also incorporated into their post-secondary transition process (Mull & Sitlington, 2003).

Word processing applications. Word processing and other computer software have been effective on improving writing skills of SWD. More specifically, word processing applications can enhance poor handwriting, spelling, grammar, and editing skills that SWD often struggle with (Hasselbring & Glaser, 2000; Lewis, 1998, 2000, 2005). For example, the *Enhancing Writing Skills Project* conducted by Lewis, Graves, Ashton, and Kieley (1998) examined the effects of using word processing tools to improve the writing skills of SWD in fourth to twelfth grades. The word processing applications used in the project included speech synthesis, word prediction, and spelling and grammar checking functions. Lewis and colleagues concluded that word processing technology helped SWD improve their writing speed, quantity, quality, and accuracy and their attitudes toward the writing process as well.

Commercially available word processing software can also play as a compensatory tool on the writing skills of SWD. Hetzroni and Shrieber (2004) examined the effectiveness of *Microsoft Word 2000*[®] on academic outcomes of three junior high school SWD. The results indicated that all participants benefited from the word processor in improving their spelling, organizing, and reading skills. For example, “the use of the red underline feature and the availability of the spell checker increased their awareness of the existence of their errors in the text” (p. 152). Hetzroni and Shrieber concluded that the

technology application enabled SWD to take control over their assignments while using their strengths instead of their deficits.

Computer-assisted instruction applications. Computer-assisted instruction (CAI) is one of the instructional approaches using computer applications. CAI is defined as the use of a computer to provide instructional contents, and it has been the most typical application of educational technology for SWD (Okolo, 1992; Poplin, 1995; Seo & Bryant, 2009). CAI usually consists of drill, practice, and self-tutorial applications, simulation tasks, and instructional games, and its applications have been recognized as promising instructional tools for SWD (Hofmeister, 1984; Lewis, 2000; Seo & Bryant, 2009; Soe, Koki, & Chang, 2000). However, little research to date has shown its effects on academic performance of SWD (Seo & Bryant, 2009).

One of the few evidence-based CAI examples is *READ 180*, published by Scholastic, Inc. (Davidson & Miller, 2002). Hasselbring and Bausch (2005) discussed that *READ 180* is an individualized reading intervention to enhance overall reading skills of SWD. According to Davidson and Miller, instruction and practice in *READ 180* is customized based on individual student abilities to prevent frustration that SWD often have in reading activities. *READ 180* includes videos to present students with the context necessary to help them understand new vocabulary words and academic language by presenting images and background information. The materials are age appropriate, so students are more likely engaged and motivated and are able to access grade level reading contents (Davidson & Miller, 2002; Hasselbring & Bausch, 2005).

Hypertext and hypermedia applications. According to Hasselbring and Glaser (2000), technology enables students to make connections between different types of

information, such as text, photographs, television, video, sound, graphics, and computing, and this type of connection is referred to hypertext or hypermedia. Hypertext (or hyperlinks) is another form of CAI applications, but it further provides students with immediate access to vast amounts of information by the click of a computer mouse (Hasselbring & Glaser, 2000; Higgins & Boone, 1990). Studies conducted with high school SWD (Higgins & Boone, 1990; Higgins, Boone, & Lovitt, 1996) revealed that the use of hypertext improved academic performances on grade-level social studies daily quizzes, posttests, and retention tests. As Hasselbring and Glaser pointed out, hypertext applications enable students to create “meaningful learning experiences through quick and easy links between new and previously learned information” (p. 108).

Text-only technology applications (i.e., hypertext) hold a promise to help SWD improve academic performance; yet educational applications need to keep up with the rapid change of the technology (Babbitt & Miller, 1996; Higgins et al., 1996). In addition, Higgins and colleagues argued that multi-information applications (i.e., multimedia) are more effective on student retention skills than text-only information support (i.e., hypertext). The concept of multimedia as instructional technology has been extended to media-enhanced learning environments. Hasselbring and Glaser (2000) argued that the educational use of multimedia applications would promote students’ conceptual understanding “by linking visual imagery and sound effects to information that is difficult to understand when presented in text alone” (p. 109).

Based on the promising benefits of multimedia-based learning approach, the Cognition and Technology Group at Vanderbilt ([CTGV], 1990, 1997) developed Anchored Instruction (AI) to improve academic skills, such as literacy, mathematics, and

problem-solving skills, in an engaging, supportive environment (Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990; Hasselbring & Goin, 2004). AI involves the use of video as a context for instruction, which helps students build mental models from text (CTGV, 1991). Because SWD often bring limited subject-related background knowledge to the classroom, incorporating dynamic images and sounds are especially helpful to address background knowledge problem of SWD (Hasselbring & Glaser, 2000). Studies showed that AI has been successfully implemented for SWD and improved their mathematical performances (Bottge, 1999; Bottge & Hasselbring, 1993).

Each of the above computer technology applications has shown significant impacts on academic performance for SWD. However, such applications can be used in combination with another type of technology application. Based on the pedagogical concepts of AI, Bottge and colleagues developed Enhanced Anchored Instruction (EAI) in which students are first presented with multimedia-based mathematics problems and then applied their skills to hands-on-based, contextualized learning activities (see Bottge, Grant, Stephens, & Rueda, 2010; Bottge, Ma, Gassaway, Butler, & Toland, 2014; Bottge, Rueda, Grant, Stephens, & LaRoque, 2010; Bottge, Rueda, LaRoque et al., 2007; Bottge et al., 2015).

Other Technology Applications

Hand-held mobile device. Over the past decades, technological advances have changed our world in which people access to vast amounts of web-based information with the touch of fingertips on a hand-held device, and these technology tools have reshaped the area of education as well (Vinu, Sherimon, & Krishnan, 2011). However, limited studies have examined the effects of mobile devices on academic achievement of

SWD. Retter, Anderson, and Kieran (2013) conducted a study to investigate the effectiveness of a tablet computer and software (e.g., *iPad* and app) on reading skills of high school SWD. The results indicated that the use of *iPad* and app was effective to increase reading comprehension and vocabulary skills.

3D printers. Another technology application that has been recognized to have potential benefits in the education fields over the past several years is 3D printers (Lacey, 2010; Murray, 2013). 3D printers already have been a part of school curriculum, especially in STEM (science, technology, engineering, and math) education (Sheridan et al., 2013; Sheridan et al., 2014), and there has been some research to examine the effects of 3D printers on mathematics performance of elementary school students (Berry, Bull, Browning, Thomas, Starkweather, & Aylor, 2010). In Berry and colleagues' study, although it was not conducted with SWD, 3D printing technology was used to introduce engineering design concepts associated with mathematical contents. The authors found that 3D printing technology was successfully integrated into elementary curriculum and used as an authentic context for teaching students.

For SWD, Lipson (2007) stated that 3D printing (or rapid prototyping) technology can improve their abilities that they often experience with the use of 2D pictures or abstract concepts. Cass and colleagues (2003) revealed that researches have shown the effects of hands-on materials on the acquisition and retention skills. The majority of literature employed concrete-semiconcrete/representational-abstract (CSA or CRA) teaching sequence with the use of 3D printers, and researchers argued that learning spatial and physical concepts is enhanced through concrete rather than abstract learning experiences (Butler, Miller, Crehan, Babbitt, & Pierce, 2003; Maccini & Ruhl, 2000;

Morin & Miller, 1998; Scheuerman, Deshler, & Schumaker, 2009). Lipson (2007) stated that 3D visualizations would bring the technology trend to classrooms and replace traditional hands-on manipulatives in teaching and learning special knowledge and skills. Lipson also argued that it is not only because 3D printers produce hands-on materials, but 3D printing technology also creates active learning environments by providing accessible and customized physical models that meet specific needs of SWD.

Mathematics Problem-Solving Interventions

Graduated Instructional Sequences

Researchers have shown that graduated instructional sequences can improve problem-solving skills among SWD, particularly SMD by approaching a mathematical concept at different cognitive levels (Butler et al., 2003; Maccini & Ruhl, 2000; Morin & Miller, 1998; Scheuerman et al., 2009). Graduated instructional sequence has been represented as Concrete-Representational-Abstract (CRA) or Representational-Abstract (RA), Concrete-Semi-concrete-Abstract (CSA), and Concrete-Pictorial-Abstract (CPA) in literature. This instructional approach has three instructional stages in common: (a) concrete, (b) semi-concrete (representation), and (c) abstract. The sequence moves through three stages in order, and each stage builds on the previous stage to promote student problem-solving skills. The first stage is the concrete level, and it involves manipulatives or other three-dimensional objects that students can handle. Representational level includes two-dimensional drawing (e.g., chart, diagram, or graph) as visual cues. Abstract stage refers to a symbolic level in which only numbers, mathematical operations, or symbols are used.

Research examples. Several researchers have examined the effects of graduated instructional sequence approaches. Morin and Miller (1998) conducted a single-subject study to evaluate the effectiveness of CRA combined with an instructional strategy on improving problem-solving performance as well as computational skills. *Multiplication Facts 0 to 81* (Mercer & Miller, 1992) was used to teach multiplication facts within CRA, and a mnemonic strategy was implemented for multiplication-related word problems. The mnemonic approach used in the study was *DRAW*: (a) discover the sign; (b) read the problem; (c) answer, or draw and check; and (d) write the answer. In addition, the *Multiplication Facts* contained teaching materials such as organizers, demonstrations, guided practice with feedback, and independent practice with feedback. The teaching materials were delivered through direct instruction within CRA consequence.

Three seventh-grade SWD participated in a special education classroom. All participants had been identified as having intellectual disabilities as their primary disabilities, and two students had visual impairment or physical disability as secondary disabilities. All participants had shown significantly low math performing in computation and problem solving. The intervention focused mainly on multiplication facts (i.e., computational skills) using CRA consequences (e.g., manipulatives, visual cues), and the word problem in the study contained key words (e.g., groups, blocks) as clues of multiplication. The results showed that overall student performance was significantly increased, but the performance across the participants was lower in problem-solving practices than computation lessons.

Maccini and Ruhl (2000) conducted a single-subject study to investigate effects on teaching algebraic subtraction when CSA approach is integrated with other teaching

strategies. Problem-solving approaches used in the study included *STAR* mnemonic strategy similar to Morin and Miller's (1998) *DRAW* strategy. The mnemonic strategy provided students with cues in problem-solving process: (a) search the word problem, (b) translate the words into a mathematical equation, (c) answer the problem, and (d) review the solution. CSA (i.e., graduated instructional sequence) approach, general problem-solving strategies (e.g., modeling, guided/independent practice, feedback), and self-monitoring strategies were combined with the mnemonic strategy.

Three eighth-grade students participated in the study. All participants were SMD and had received specialized math instruction due to their difficulties in math. Results indicated that all three participants successfully improved problem-solving skills involving algebraic subtraction concepts, and one student even exhibited generalized treatment effects in new instructional structures. However, students had difficulties to remember some stage of *STAR* mnemonic strategy, and this remained as one of the study limitations.

Butler and colleagues (2003) investigated the effects of two forms of graduated instructional sequence (e.g., CRA or RA) on fraction-related procedural and problem-solving skills. The study was conducted in resource settings, and there were 50 students participating in the study. Participants were in sixth- to eighth-grade SMD. The results indicated significant improvement on procedural skills from both treatment groups, but no clear understanding of fraction concepts, abstract problems, and word problems was shown. Post hoc analysis revealed that students from CRA group demonstrated better conceptual understanding than RA group, but this was significant only in quantity tests.

Overall, SMD could benefit from both CRA and RA approaches for positive attitudes toward mathematics and fraction-related word problems.

Scheurmann and colleagues (2009) implemented CRA intervention through explicit instruction to improve algebraic problem-solving skills among 14 middle school SMD in both general education and special education settings. Participants were in grades six through eight, were diagnosed with learning disabilities, and exhibited low performing in various math achievement assessments. The results showed improvement of problem-solving skills and generalization of the skills to a variety of situations. The findings of the study supported the effectiveness of CRA when it has been taught explicitly.

Strength and weakness. The use of concrete materials has been common in teaching mathematics concepts. According to NMAP (2008), physical representations help students connect mathematics concepts to real-world experiences. Graduated instructional sequences allow students to make sense of physical objects by presenting hands-on learning materials. Then, representational pictures help them model the manipulatives at the next level, and eventually abstract sequence is introduced with numbers and symbols. As the instruction proceeds to the next stages (e.g., from concrete to semi-concrete), the previous stage serves as a scaffolded learning support so that students can progress from the physical representation to the abstract concept. SWD more likely benefit from the scaffolded format as it gradually releases responsibility of learning to students so that students take control of their own learning (NMAP, 2008).

The sequence of this instructional approach might cause a transitioning issue for some SMD, when it is implemented solely. Although students have their learning control,

they need to demonstrate thorough understanding at each stage so that they can progress to the next stage. More abstract and difficult concepts should be introduced only after students master or internalize easier and more concrete representations at the each stage. In addition, transitioning from concrete or representation understanding to abstract concepts might be a too broad cognitive leap and cause confusions or misconceptions. SMD often lack appropriate mathematical concepts from their early ages, so additional instructional supports might be required to refine mathematical understanding when using the graduated instructional sequences.

Schema-Based Instructions

Researchers in mathematics education agreed that visual representations play important roles in improving mathematical understandings (Gersten et al., 2009; Griffin & Jitendra, 2009). According to Hegarty and Kozhevnikov (1999), there are two different types of visual imageries. One is schematic (e.g., spatial relationships between objects) imagery, and the other is pictorial (e.g., visual appearance of the objects) imagery. Based on the concept of heuristic developed by Polya (1945), researchers have attempted to evaluate the efficacies of schema-based strategy instruction (SBI) focusing on problem-solving skills.

Research examples. Jitendra, Hoff, and Beck (1999) investigated the effectiveness of SBI on problem-solving performance among four middle school SMD. This study was to replicate the earlier research (Jitendra, Griffin, McGoey, Gardill, Bhat, & Riley, 1998) in which SBI was implemented to improve problem-solving skills among elementary school SMD. In Jitendra and colleagues' study (1999), four middle school students participated, ranging in grade six to seven. Three SBI diagrams (change diagram,

group diagram, and compare diagram) were delivered through a direct instruction approach, and two different intervention stages were implemented (one-step word problems and two-step word problems). Twenty-one third-grade average-achieving students were involved in the study as a comparison group for testing, and the study took place in a special education resource room. The results of the study indicated SBI was effective to improve problem-solving skills in solving one- and two-step word problems across the participants.

Jitendra and colleagues (2002) extended the previous study described above. Jitendra and colleagues conducted a single subject study with four eighth-grade students. The participating SMD received learning support for mathematics instruction. The instructional materials included schema diagrams and multiplication/division word problems. Four experimental phases were implemented, including baseline, problem schema identification condition (e.g., story situations with problem schemata diagrams), problem solution condition (e.g., problem schemata within word problem context), and generalization and maintenance. Results of the study indicated that all participants improved their problem-solving performance. The findings of the study supported the previous research showing the efficacy of SBI on conceptual understanding of problem solving (Jitendra et al., 1998; Jitendra et al., 1999).

Xin and colleagues (2005) also extended Jitendra and colleagues' studies (Jitendra et al., 1999; Jitendra et al., 2002) and investigated the differential effects of two problem-solving instructional approaches. The first approach was SBI in which students were taught to identify the problem structure and use a schema diagram to represent and solve the problem. The second approach, on the other hands, involved the use of a general

strategy, and students learned to draw semi-concrete pictures to represent information in the problem and facilitate problem solving. The general strategy was adapted from commercial mathematics textbooks, and it had four steps: (a) read to understand, (b) develop a plan, (c) solve, and (d) look back.

The participants in the study were 22 middle school SMD, and the participating students were consisted of 18 with learning disabilities, one with severe emotional disorders, and three were at risk for mathematics failure. Results showed that students in the first instructional approach (SBI) performed significantly better than the second approach (general strategy) on all measures of acquisition, maintenance, and generalization. The findings of the study support the effectiveness of SBI in solving mathematical word problems.

Van Garderen (2007) conducted a single subject study to examine the effectiveness of SBI on word problems. Three eighth-grade SMD participated in the study, and SBI intervention was delivered in a separate classroom. As a form of SBI, diagrams were used to help students visualize the structure of problem in order to simplify complex situations. The results indicated all students improved word problem performance, generalized to a different type problem, and satisfied with the instruction. Van Garderen concluded that a schematic diagram was more beneficial and associated to success in mathematical problem solving than a pictorial diagram.

Krawec (2014) investigated the differential effects of visual representation with paraphrasing accuracy on problem-solving performance of SMD. There were 84 eighth-grade students from four middle schools participated in the study. Among the participants, 25 were SMD, 30 had struggled in math or showed low achieving from math assessments,

and the rest 29 were average-achieving students. The instructional intervention used in the study was a form of visual representation (pictorial imagery instead of schematic) followed by a paraphrasing strategy. For example, students were first asked to explain a problem in their own words and then to identify important information to solve the problem. Then, students were directed to draw a picture that would help them solve the problem. The results showed that all students improved problem-solving performance regardless of their achievement levels, and mathematics problem-solving skills were not limited by their disability status. The findings of study supported the efficacy of visual representation on math problem solving, and Krawec concluded “effective problem solving begins with the problem representation phase” (p. 105).

Strength and weakness. The studies above showed that SMD could benefit from explicit schema instruction in problem solving. Although the schemas were varied from study to study, the nature of SBI helped students improve recognizing a problem’s schema and solve word problems by using visual imageries such as diagrams. Since SMD often struggle with reading comprehension, they more likely experience difficulties in solving mathematics problems represented in text formats (Fuchs, Fuchs, Hamlett, Lambert, Stuebing, & Fetcher, 2008). The use of schematic diagrams in SBI was particularly effective for students to identify problems and set up a plan during problem-solving process.

As described in the studies above, SBI was effective on visualizing text-base information when solving word problems. However, the studies did not attempt to decrease the use of schematic diagrams over time or to generalize the strategy in other problem-solving situations. Unless diagrams should be used as a tool to solve problems,

students might become too dependent on “the” diagram. This limitation less likely promotes students’ problem-solving skills in unfamiliar situations and provides less opportunity to “extend what they already know” (NCTM, 2000, p. 52).

Cognitive Strategy Instructions

Researchers in mathematics education with special education perspectives (Dalziel, Thompson, Grismer 2008; Ketterlin-Geller, Chard & Fien, 2008) have argued that cognitive strategy instruction (CSI) may be one of the most effective instructional approaches for SMD along with graduated instructional sequences (CRA) and visual representations (SBI). According to Dalziel and colleagues (2008), CSI is an instructional support in order for students to direct their actions to meet learning goals (e.g., solving problems). CSI emphasizes cognitive process, such as metacognitive skills, through which students monitor and evaluate their problem-solving strategies (Montague, 2008), and it involves identifying and utilizing effective strategies that are particularly relevant to comprehension (Dalziel et al., 2008). CSI often includes written cues or prompts (e.g., mnemonic) to guide students through the mathematics problem-solving process (Bryant, Bryant, Gersten, Scammacca, & Chavez, 2008; Hutchinson, 1993a; Jitendra et al., 2002; Ketterlin-Geller et al., 2008; Owen & Fuchs, 2002; Xin et al., 2005).

Research examples. Montague (1992) conducted a single-subject study to investigate the effect of CSI and metacognitive strategy instruction (MCSI) on problem-solving performance of six middle school SMD. Using a multiple baseline, across-subjects design, two types of CSI treatments were implemented. The first approach focused on direct instruction through CSI (e.g., demonstration and guided practice), while the second approach focused on self-awareness of cognitive knowledge (i.e., MCSI).

Montague introduced CSI to participants first, and then added MCSI so that participants received the combination of CSI and MCSI. The results showed that CSI combined with MCSI was more effective than CSI alone. Montague argued that adding MCSI approach was significantly effective since it helped students “direct and regulate cognitive processes and strategies during problem solving” (p. 230).

A decade later, Montague (2003) developed a standard mathematics curriculum, called *Solve It!*, to improve problem-solving skills of SMD based on the previous studies using CSI and MCSI (Montague, 1992; Montague et al., 1993). *Solve It!* contained sequenced scripted lessons through which students are explicitly taught how to apply CSI and MCSI approaches in the context of mathematics problem solving. Seven cognitive process were embedded in *Solve It!* as CSI components (read, paraphrase, visualize, hypothesize, estimate, compute, and check), and corresponding self-regulation strategies were included as MCSI (e.g., giving self-instructions, asking self-questions, and monitoring self-performance). The ultimate goal of *Solve It!* was to help students internalize the cognitive processes (CSI) and self-regulation strategies (MCSI) for them to use the strategies during problem solving.

Using *Solve It!*, Montague and colleagues (2011) conducted a study to investigate the differential effects of *Solve It!* on students’ mathematics performance across their achievement levels. A total of 37 general mathematics teachers and 779 eighth-grade students from 40 schools participated in the study. Participants’ mathematics achievement levels were varied, as total of 319 students in the intervention group were consisted of 32 SMD, 178 students with low achievement in mathematics, and 109 students with average achievement in mathematics. The results showed that the

intervention significantly improved problem-solving skills across the participants regardless of their previous achievement levels. The study supported that the intervention can be successfully implemented for SMD in inclusive education settings as well.

Krawec, Juang, Montague, and Kressler (2013) also investigated the effectiveness of *Solve It!* on problem-solving performance among middle school SMD over two years. Participants included 161 seventh- and eighth-grade students including 77 SMD. The results from both studies showed that all students from the intervention group significantly improved problem-solving skills compared to students from the comparison group. Krawec and colleagues concluded that *Solve It!* had more impact on average-achieving students than low-achieving students or SMD.

Strength and weakness. Studies above demonstrated that CSI was effectively embedded in the curriculum for SMD in general education settings over time. CSI typically involves the use of written cues and prompts to improve word problem-solving skills. Especially, *Solve It!* helps students, regardless of achievement levels, develop the necessary cognitive and metacognitive processes and strategies that good problem solvers use. Krawec and colleagues (2013) argued that CSI approach makes “students become increasingly independent in their application of the routine, ultimately internalizing the processes in a flexible way based on task demands” (p. 81).

According to Roberts, Torgesen, Boardman, and Scammacca (2008), unfortunately, SMD often have difficult time with CSI and MCSI approaches. Roberts and colleagues argued that SMD either do not know the effective strategies or do not actively utilize the strategies during problem-solving process even though they know the strategies. This might be because cognitive strategies focus on “increasing their repertoire

of effective strategies” (Krawec et al., 2013, p. 86) that are assumed to be essential to effective problem solving. In such case, students are asked to copy what experts demonstrate, but they are not encouraged to develop fundamental understanding of mathematics concepts. As Bottge (1999) pointed out, this approach in which students “follow the cognitive trail of expert problem solvers” (p. 82) might cause maintenance and generalization problems.

Anchored Instruction

Researchers discussed that traditional math instructions (e.g., teaching facts or formulas to be memorized) often cause students’ inert knowledge problem as results of failure to maintain and generalize what they have previously learned (Bottge, 1999; Bottge & Hasselbring, 1993; Brown, Collins, & Duguid, 1989; CTGV, 1990). According to Whitehead (1929), inert knowledge is a type of knowledge that is “merely received into the mind without being utilized, or tested, or thrown into fresh combinations” (p. 1). Students with inert knowledge have stored information in their memory and can recall it when explicitly asked. However, they cannot use the relevant information in other problem-solving situations. To overcome the inert knowledge problem, CTGV developed AI based on situated learning theory. AI creates learning environments in which students receive the new information as a tool rather than facts or formula to memorize. AI is more likely delivered through visual macrocontexts (e.g., story anchor) than textual formats, and it contains embedded data that provide student real-life problem-solving situations.

Research examples. Most of the studies using AI for SMD were conducted by Bottge and his colleagues. Bottge (1999) conducted a study to investigate the effect of AI

on mathematics problem-solving performance including computational skills, word problems, and contextualized problems. A total of 66 eighth-grade students participated in the study, including 17 from a remedial math class and 49 from pre-algebra class. Five SMD and 12 students were placed in the remedial class due to low math performing. Only two SMD were from pre-algebra class. The study was aimed to compare two different instructions (word problem instruction and contextualized problem instruction).

While students from contextualized instruction group were taught using video-based anchor with embedded problems, students from word problem instruction were taught with general guide (adapted from Rosenshine & Stevens, 1986) and modified version of Montague's (1992) cognitive strategy training model, which includes paraphrase the problem, hypothesize, estimate, compute, and check. Results of the study indicated significant improvement on contextualized problems and transfer tasks from both contextualized instruction groups (general and remedial classes), but no significant differences were found on computation tests. The results supported that the use of contextualized instruction could improve problem-solving skills of students in both general and special education settings.

Based on the concepts of AI, Bottge and colleagues further developed EAI by integrating hands-on activities into AI approach (Bottge et al., 2001; Bottge, Rueda, Kwon, Grant, & LaRoque, 2009; Bottge, Rueda, LaRoque et al., 2007; Bottge, Rueda, Serlin, Hung, & Kwon, 2007). Bottge, Rueda, Grant and colleagues (2010) investigated effects of EAI combined with informal instruction (i.e., explicit computer-based instruction) on fraction-related computation and problem-solving performance among SMD. There were 54 middle school students participated in the study. All participants

were placed in self-contained classroom for mathematics, and most of them were SMD. In their study, computational and problem-solving skills were taught together through combined intervention of EAI and informal instruction. EAI contained real-world problems followed by video-based story (i.e., anchored problems), hands-on projects, and additional practice on related mathematics concepts. More specifically, Bottge and colleagues stated that:

Each anchored problem consists of several subproblems embedded in authentic contexts. Students must develop an understanding of the overall problem, identify the relevant pieces of information..., and finally integrate this information into a solution that makes sense. ... Thus, EAI problems directly immerse students in problem contexts, which is an important benefit for students who have difficulty in reading and math (Bottge, Rueda, Grant et al., 2010, p. 419).

The results indicated that both forms of EAI (either combined with informal instruction or EAI by itself) improved students' problem-solving performance. When EAI was implemented with explicit computational instruction, it was more effective on enhancing computational skills than EAI by itself. The findings supported Woodward's (2004) argument that math instruction in special education should maintain a balance between direct and constructive perspectives.

Strength and weakness. According to Woodward and Montague (2002), anchored instruction approach (either AI or EAI) is one of the few research-based mathematics interventions to address the inert knowledge problem. As discussed above, anchored instruction approach helped students develop useful knowledge rather than inert knowledge (Bransford et al., 1990). Bottge and colleagues' studies showed that students

were able to maintain and generalize their problem-solving skills in other contexts and over time.

Anchored instruction approach has some disadvantages as well. Bottge and colleagues focused mainly on improving students' problem solving in their earlier studies (Bottge et al., 2002; Bottge, Rueda, Serlin, Hung, & Kwon, 2007). Bottge, Ma, Gassaway, Butler and colleagues (2014) once discussed the weak effects of EAI on students' fractions computation skills. Another disadvantage might be caused by the complexity of EAI contents. It is well documented that performances of SMD are below their grade level. More specifically, Fuchs and colleagues (2005) stated that the mathematics competence of SMD progresses about 1 year for every 2 years in school. When curriculum contents are too difficult, some students might copy answers from other high-performing students or do not participated at all. Although newer version of EAI has been developed to improve computation skills of SMD, they more likely struggle with EAI contents when they do not reach a certain level of basic mathematics. However, this issue should be addressed carefully, because "teaching concepts for understanding does not always have to wait until all related procedural skills are mastered" (Bottge, Rueda, LaRoque et al., 2007, p. 107).

Enhanced Anchored Instruction

From situated learning perspectives, students should apply what they have previously learned to realistic contexts and transfer basic skills and knowledge to other situations in their everyday lives (Wilson & Myers, 2000). Based on this notion of situated learning theory and the pedagogical concepts of AI (CTGV, 1990, 1997), Bottge and his colleagues have specifically studied teaching and learning of mathematics

through video-anchored software and hands-on applications in order to improve both computational and problem-solving skills specifically for SMD. As an enhanced form of AI originally developed by CTGV, EAI has critical implications for teaching SMD.

First, EAI situates problems in authentic and meaningful contexts in which students can relate to real-life problems. The purpose of EAI is to create a dynamic learning environment in which students are directed to realistic problems through video anchor and hands-on applications. EAI allows students to be engaged in meaningful contexts, to construct their knowledge with multiple perspectives through collaborative work, and to transfer their knowledge into other learning situations. Second, the ultimate goal of EAI is to help students become independent problem solvers by allowing them to experience some of advantage of in-context apprenticeship training. Students are encouraged to follow the way experts think and solve problems and understand why, when, and how to use various concepts and strategies to solve complex problems in realistic situations.

Contrary to traditional situated learning theory which mainly focuses on the effect of social interact, however, EAI emphasizes knowledge acquisition in terms of individual internal mental processes as well. For example, Bottge (2001a) revealed the importance of explicit teaching approach to ensure students to develop basic mathematical knowledge, and how individual students can overcome their inert knowledge. This perspective focusing on individual's cognition might counteract the notion of traditional situated learning. However, EAI was developed to help individual students not only construct essential knowledge embedded in situations, but also transfer their inert knowledge into practical knowledge through problem-solving processes in realistic

situations. EAI problems were especially designed to improve the problem-solving skills of SMD through the meaningful, explicit, informal, (de)situational, social, and teacher-specific instructions as the key model illustrates (see Figure 1). The major focus of EAI is on developing a range of individual students' mathematical skills, but social and cultural supports play important roles in improving student problem-solving skills within the intervention process (Bottge, 2001b; Bottge, Heinrichs, Chan, Mehta, & Watson, 2003).

Main Characteristics of EAI

In their recent papers, Bottge and colleagues described the important characteristics of EAI as realistic problems that are embedded in contexts and presented in video-based formats, which distinguish itself from other instructional interventions (Bottge, Ma, Gassaway, Toland et al., 2014; Bottge et al., 2015). Bottge's previous studies showed that EAI allowed students first engage in multimedia lesson and then solve contextualized, or hands-on, problems by using information embedded in video anchor (Bottge et al., 2001; Bottge et al., 2009; Bottge, Rueda, LaRoque et al., 2007; Bottge, Rueda, Serlin et al., 2007). In addition, another critical feature of EAI is its ability to provide modeling and scaffolding (i.e., cognitive apprenticeship) to SMD (Bottge, Heinrichs, Mehta, Rueda, Hung, & Danneker, 2004; Bottge et al., 2010).

Multimedia format. The first characteristic of EAI is video-based instructions and problems delivered in a multimedia format (Bottge et al., 2001; Bottge et al., 2009, Bottge, Rueda, Laroque et al., 2007; Bottge, Rueda, Serlin et al., 2007). According to Bottge, Rueda, Serlin et al. (2007), EAI requires students "first solve a problem in a multimedia format" (p. 32) based on the concepts of AI. When AI was developed by CTGV (1990), a visual format was preferred to a textual format because of its abilities (a)

to develop pattern recognition skills, (b) to allow a more veridical representation of events (e.g., dynamic, visual, spatial), and (c) to provide random-access capabilities. CTGV argued that video would play an important role in helping low-achieving students develop rich mental models of the problem situations, and this is beneficial to any students who have little knowledge in the domain of interest.

Since EAI is based on AI, EAI has the same benefits from the use of a visual format. Through the instructional units of EAI, students are introduced with video-based instructions and problems. A series of direct instructions are delivered (e.g., adding and subtracting fractions), or video stories show mathematical formulation (e.g., calculating speed) and ask to solve complex mathematical problems at the end of the video stories (e.g., finding the most efficient way to build skateboard ramp). The video-based anchors help students visualize abstract mathematical concepts and provide with multiple practice opportunities (Bottge et al., 2015).

Embedded information. EAI, like AI, is characterized by embedded information to solve the problems presented in the multimedia formats. Throughout the video, students are exposed to random information. CTGV (1990) argued that factual data embedded in the video become important when the problems are introduced. This type of instructional design creates a learning environment, which encourages students to identify relevant facts, procedures, and concepts, to generate what they need to know, and to interact with video anchors (e.g., scanning back and forth) in order to solve the problems correctly.

For example, one of EAI's instructional units (*Fraction of the Cost*) includes a short video story. Throughout the video, mathematical facts, procedures, and concepts are

introduced, including calculating sales tax, measuring and converting length, and computing fractions. When a problem is shown (e.g., to build a skateboard ramp) at the end of the video, students need to identify relevant information (e.g., required materials, budget) that are embedded in the video anchor.

Contextualized problem. The notion underlying EAI is that teaching and learning must occur in authentic and meaningful contexts in which students can relate to real-life problems. According to Bottge and colleagues (2009), EAI “extends learning beyond the multimedia contexts by having students solve problem embedded in applied projects” (p. 530). This might be a critical feature that distinguishes EAI from the previous version of AI developed by CTGV. In EAI, instructions on a video anchor are linked with an applied task (Bottge et al., 2001), and EAI directly immerses students in problem-solving situations through a combination of multimedia and hands-on contexts (Bottge, Rueda, LaRoque et al., 2007).

Through the series of instructional units of EAI, students can engage in meaningful academic activities and apply mathematical concepts to real-world problems. Unlike AI, students not only engage in multimedia format, but they also apply what they have previously learned in related hands-on problems (Bottge, Rueda, Serlin et al., 2007). For example, students first participate in a multimedia-based instruction, called *Kim’s Komet*, which is originally developed by CTGV (*Jasper Woodbury*). After solving problems in *Kim’s Komet*, students are directed to an authentic problem-solving instruction unit, called *Grand Pentathlon*. The problem-solving situation is similar to AI, but EAI provides with contextualized problems through hands-on applications while AI has video-based problems solely through multimedia format.

Cognitive apprenticeship. Although EAI can be applied to all students at any achievement level, EAI is to improve math skills specifically for low-achieving students, including SMD. Researchers argued that specialized instruction is critical in order for SMD to perform at an adequate level (Kroesbergen & van Luit, 2003), and additional instruction is necessary to help SMD perform at the level of their average-achieving peers (Bottge et al., 2004). Without additional support to mediate classroom instructions, SMD more likely play passive roles in their learning, and their progress has been slower than SWOD (Woodward, 2004).

Based on the concepts of cognitive apprenticeship (Schoenfeld, 1985), EAI has been designed to help teachers individualize instructions in order to meet the needs of individual SMD while providing appropriate scaffolds (e.g., organizational strategies and other supporting materials) to support the students' own effort (Bottge, Rueda, LaRoque et al., 2007; Bottge, Rueda, Serlin et al., 2007). For example, students observe the work of experts (e.g., teachers or high-performing peers), which provide them with models of how to construct their graphs in the multimedia-based unit (*Kim's Komet*) and its contextualized problem (*Grand Pentathlon*). In addition, teachers provide additional support by providing just-in-time instruction on any concept that students have particular difficulties (e.g., calculating speed, plotting variables).

Effects of EAI Curriculum

Bottge and colleagues have conducted number of studies to examine the effectiveness of EAI among SMD for more than a decade. The results across the studies indicated that EAI curriculum improved student computation and/or problem-solving skills (Bottge, 1999; Bottge & Hasselbring, 1993; Bottge et al., 2003; Bottge, Ma,

Gassaway, Butler, & Toland, 2014; Bottge et al., 2010; Bottge, Rueda, LaRoque et al., 2007), retained what they have previously learned in different contexts or several weeks later (Bottge & Hasselbring, 1993; Bottge et al., 2001; Bottge et al., 2004; Bottge Rueda, LaRoque et al., 2007), promoted students' motivation and engagement with meaningful learning activities (Bottge et al., 2002; Bottge, Rueda, LaRoque et al., 2007), and provided cognitive supports to address limited working memory (Bottge, Ma, Gassaway, Butler, & Toland, 2014; Bottge et al., 2010; Bottge, Rueda, LaRoque et al., 2007; Bottge, Rueda, Serlin et al., 2007).

One of the earliest attempts with EAI can be found in the study conducted by Bottge and Hasselbring (1993). Bottge and Hasselbring used a video anchor and an interactive videodisc program to improve fraction computation and problem-solving performance and knowledge transfer. A total of 36 ninth-grade students participated in the study, and 17 of the participants were SWD receiving special education services due to their disabilities. The results indicated that EAI not only produced improvement of student performance on computation and problem solving, but it also enabled learning transfer to occur three weeks after the instruction.

Results from Bottge's later studies showed that EAI was particularly effective in developing students' transfer and maintenance abilities along with their problem-solving skills (Bottge, 1999; Bottge et al., 2001; Bottge et al., 2004). In the study conducted in 1999, Bottge used video anchor to improve performance in transfer tasks as well as computation and problem-solving skills for SMD. Their ability to transfer what they have previously learned in EAI curriculum was evident from the study findings. Bottge's other studies also supported that SMD matched the performance of SWOD on the problem-

solving tests and maintenance tests (Bottge et al., 2001), or demonstrated maintenance skills several weeks later (Bottge et al., 2004). From the findings of the studies, Bottge and colleagues (2004) argued, “maintenance and transfer of skills are more likely to occur in motivating contexts, when students put the value on solving problems” (p. 187). Through the curriculum of EAI, students could engage in meaningful academic activities and apply their problem-solving skills to real-world problems.

It is a fundamental idea underlying EAI that teaching and learning must occur in authentic and meaningful contexts in which students can relate to real-life problems (Bottge et al., 2004). However, the ignorance of explicit computation instructions might cause the weak effects on student computation performance for SMD as found from the studies conducted with the earlier version of EAI (Bottge et al., 2002; Bottge, Rueda, Serlin et al., 2007). Bottge, Ma, Gassaway, Butler and Toland (2014) discussed that it was “naïve to expect change in computing performance given the complexity of fractions” (p. 239) among SMD. Low performance on computation skills might also cause another disadvantage that students copied the work of more capable students or did not participate at all (Bottge et al., 2002). Bottge, Rueda, Serlin, and colleagues (2007) argued that it is because the difficulty level of the contextualized problems might be too high for SMD, and the complexity of EAI curriculum might overload their working memory. According to Mayer and Moreno (2003), cognitive overload is one of the common challenges of multimedia-based instructions, and such instructions should be designed in ways that minimize any unnecessary cognitive load. Mayer and Moreno suggested to break down into small segments or to provide pretraining in which students learn and apply prerequisite skills through learning activities.

To address the cognitive overloading issue of EAI curriculum, Bottge and colleagues (2010) added “pretraining” explicit instruction modules of computer-based and hands-on computation, called *Fraction at Work*. It focused on teaching difficult fraction concepts and procedures, such as fraction equivalence and adding or subtracting mixed numbers with different denominators. The results of the study conducted with *Fraction at Work* indicated significant improvement on student computation performance as well as problem-solving skills, and suggested the updated version of EAI with multimedia-based computation modules (*Fraction at Work*) reduced students’ cognitive overload.

Another evidence of cognitive support can be found in other components of EAI curriculum. Bottge, Rueda, Serlin, and colleagues (2007) argued that even if students are motivated and engaged, motivation and engagement by itself does not guarantee student learning, and successful learning rather requires structured curriculum. In addition to the pretraining unit, EAI curriculum has been broken down into small, sequential chunks (Bottge, Rueda, LaRoque et al., 2007) based on the cognitive learning theory (Mayer & Moreno, 2003). The curriculum of EAI has been developed to fit in typical class periods (e.g., 45 to 60 minutes), and daily lesson plans include warm-up exercises, sequenced but chunked main lessons, and wrap-up questions. Students with limited working memory, such as SMD, will more likely benefit from the use of EAI regardless of their level of current math skills (Bottge, Rueda, Serlin et al., 2007).

Theoretical Foundation of EAI

EAI has its origin in AI (CTGV, 1990, 1997) and its theoretical base in the teaching and learning model (see Bottge, 2001a). Because EAI was developed based on

the concept of AI, theoretical background of AI, situated cognition, would support the use of EAI in general. In addition to the situated learning theory, EAI is based upon the key theory of teaching and learning model (Bottge, 2001a). Although the key model can be applied to all students of any age, Bottge focused primarily on teaching and learning low-achieving students including SMD.

As illustrated in Figure 1, the key model is consisted of two major parts – a key and a lock – which are important conditions for successful instruction and learning. The lock implies students' qualities required for their successful learning. There are six lock pins, and they are labeled as (a) engagement, (b) foundations, (c) intuitions, (d) transfer, (e) cultural supports, and (f) student-specific. The key represents qualities of effective instructional approaches, and there are six teeth on the key. These teeth are labeled as (a) meaningful, (b) explicit, (c) informal, (d) (de)situational, (e) social, and (f) teacher-specific. For the key (e.g., teacher instruction) to successfully unlock the lock (e.g., student learning), the lock must meet all the teeth of the key. When even one lock pin is missing or too short or too long, the lock will not open. This implies that successful student learning does not occur if any of the instructional qualities is missing, or when any of the student qualities is not enhanced by a teacher instruction. The key model is not only a theoretical foundation of EAI, but it also serves as the practical guidelines for the use of EAI (Bottge, 2001a).

Meaningful learning activities and student engagement. First, providing meaningful activities is the key to lift the first pin of the lock, student engagement. Many special educators have traditionally focused on teaching declarative and procedural knowledge using direct instruction approach (Woodward, 2004). This approach not only

causes inert knowledge problem and retention problems, but it also results in disengaged students. According to Taylor and Parsons (2011), between 25% and over 66% of students are considered to be disengaged. In addition, researchers argued that procedural instructions without introducing complex or interesting problems might cause reducing students' motivation to learn math (Jones, Wilson, & Bhojwani, 1997; Means & Knapp, 1991), especially for SMD (Deci & Chandler, 1986). In order to improve student motivation and engagement, as Hiebert and his colleagues (1996) pointed out, teachers should provide meaningful activities that promote students to perceive a problem as their own. Then, students more likely take responsibility for generalizing the strategy independently without teachers' support.

Explicit instructions and student foundational skills. The second tooth of the key is explicit instruction, and it lifts the second pin of the lock, student foundational skills. Although the first lock of the key model emphasizes the need for teachers to provide students with more opportunities to engage in and solve meaningful problems, teachers should not ignore the importance of teaching declarative and procedural knowledge, especially when teaching SMD. Declarative and procedural knowledge include number facts, computational algorithms, and strategies for solving traditional text-based problems (Resnick & Ford, 1981). Bottge (2001a) argued that without a store of knowledge in basic mathematics, SMD are less likely able to figure out problem situations, even if the problems are meaningful. Bottge also addressed that students might benefit in making their computation procedures more automatically when interesting problem-solving experiences are linked to remediation of basic skills (i.e., foundations). Explicit instruction ensures that students have the foundation skills, because this form of

instruction emphasizes on “proceeding in small steps, checking for student understanding, and achieving active and successful participation by all students” (Rosenshine, 1987, p. 34).

Informal teaching and student intuition. To open the third pin of intuitions, Bottge (2001a) argued that teachers should help students rediscover and make use of informal knowledge that students bring from their lives. According to Ben-Zeev and Star (2001), however, many educators feel that traditional school instructions do not connect or build upon students’ pre-existing knowledge to the extent that it can be. Bottge argued that because traditional mathematics instructions have focused on sequential procedures or algorithms rather than making connections with student intuitions, student intuitions have been suppressed or erased by emphasis on heuristics, strategies, and rote memorization. Students should be encouraged to develop mathematical knowledge on their own (i.e., informal) instead of only being taught formal strategies by a teacher directly (Ben-Zeev & Star, 2001). Using the combination of informal teaching and formal instruction, problem solving can be a meaningful activity to students.

(De)Situating cognition and learning transfer. The fourth components of the key model include situated cognition and transfer. The importance of transfer has been recognized more than a century, but it is often difficult due to a de-situated learning context (Bottge, 2001a). For successful learning transfer, researchers have discussed the effects of situated cognition (Anderson, Reder, & Simon, 1996; Brown et al., 1989). Situated learning, as theoretical foundations of EAI, is based on the notion of “what is learned is specific to the situation in which it is learned” (Anderson et al., 1996, p. 5). This notion implies that school mathematics should emphasize the connection between

what students learn in classroom and what is needed outside of the classroom. Lave (1988) argued that traditional instructions, such as algorithms, do not transfer from school to everyday situations. Rather, sophisticated mathematical skills come from “situated-specific practices within the context of everyday life” (Bottge, 2001a, p. 107). Bottge identified the issue of context and transfer as the heart of education for SWD and argued that teachers should pay attention to the situational conditions of learning in order to help students recognize how and in what situations (i.e., contexts) to use their knowledge.

Social learning and cultural supports. The fifth pin refers to the social learning theory that learning is both a psychic and a social process (Vygotsky, 1978). Based on social constructivism and situated cognition, Brown and colleagues (1989) argued that knowledge is constructed by activities, contexts, and culture in which it is used. Lave and Wenger (1991) also argued that learning requires students to fully participate in the sociocultural practice of a community (e.g., legitimate peripheral participation). This implies that learning takes place through the social activities, historical contexts, and specific culture individuals live in. Learning is, therefore, seen as “an integral and inseparable aspect of social practice” (Lave & Wenger, 1991, p. 31), and people are taught to learn in practice by doing and by interacting with others. In other words, learning will less likely occur separately from life but in social contexts that individuals find meaningful in their everyday lives.

Other literature with situated learning perspectives emphasized that learning takes place through interactions within communities and networks of practice (Brown et al., 1989; Brown & Duguid, 2001; Wenger, 1998). Bottge (2001a) argued that active discussion and group work enable more opportunities for teachers to intervene and for

students to express and organize their thoughts as they learn. Such social and cultural supports while learning activities would help students learn the whole culture of the knowledge.

Teacher-specific and student-specific. The last tooth of the key might overlap into both the science and art of teaching. To unlock this tooth of the lock (i.e., teacher- and student-specific), teachers need to find ways to connect theory-based practice to meet the individual needs of learners. It has been challenged for special educators to find ways of delivering effective instruction that promote high expectations for SWD. Effective instruction, however, might depend on how well teachers can merge scientific findings with the artful ways they deliver their lessons. Bottge (2001a) argued that providing such instruction (e.g., fixed on student strengths while shoring up student weakness) is a challenge, but it could be met when the science and art of teaching merge. Teachers should not only create dynamic learning environments to engage and motivate students and to promote high expectations for all students, but they also have to ensure to meet unique educational needs that individual students have.

CHAPTER 3. METHODS

Setting and Participants

A total of 90 students from 6 middle schools in central Kentucky participated in this study. Out of 102 students who were first invited to the study, 12 could not participate due to missing parent consent forms. Two schools were from the same district whereas the other four were distributed across four different districts. One classroom from each school participated in the study. Three classrooms were seventh-grade inclusive math classrooms co-taught by one math teacher and one special education. The other three classrooms were eighth-grade math resource rooms taught by one special education teacher in each classroom.

Out of 90 participating students with the age range 12 to 15, 23 students were eighth grade, and 67 students were seventh grade. The study population consisted of 52 students who had identified disabilities (SWD) with Individualized Education Programs and 38 students without disabilities (SWOD). The majority of students were Caucasian consisting of 75 students, and of the remaining 15 students, seven were African American, six were Hispanic, and two were Asian. Approximately half of the population were male (49 students), while remaining 41 students were female.

Research Goal and Hypotheses

The primary goal of this research study was to examine the effectiveness of a curriculum-based technology tool called Anchored Instruction with Technology Applications (AITA) compared to Enhanced Anchored Instruction (EAI) and/or Business as Usual (BAU) on math problem-solving skills among middle school SWD and SWOD. Simple descriptive statistics were utilized to explore student demographic data and to

reflect the context of the study. In addition, inferential statistics were used to explore the extent to which three different instructional conditions impacted on student math achievement. Specifically, this study was conducted to examine the potential differential effects of three different instructional approaches in two different instructional settings: resource room and inclusive classroom. The research also investigated the interaction effect between the treatment and instructional setting as well as student variables including disability status.

Research Hypotheses

Four null hypotheses were developed for this research:

Null hypothesis 1. There are no statistically significant differences between pretest and posttest scores of students taught with the AITA curriculum compared to the BAU curriculum and/or EAI curriculum on math achievement tests of middle school SWD and SWOD.

Null hypothesis 2. There are no statistically significant differences between pretest and posttest scores of students who received math instruction in the resource room and inclusive classroom on math achievement tests of middle school SWD and SWOD.

Null hypothesis 3. There are no statistically significant differences between pretest and posttest scores affected by the interaction between the treatment condition and the instructional setting on math achievement tests of middle school SWD and SWOD.

Null hypothesis 4. There are no statistically significant differences between pretest and posttest scores based on student age, ethnicity, gender, or disability status on math achievement tests of middle school SWD and SWOD.

Research Design

A quasi-experimental factorial design combined with multiple treatments and controls with pretest (Shadish, Cook, & Campbell, 2002) was used to examine the null hypotheses. There were two independent variables (i.e., factors), and each factor had at least two levels. One independent factor was the treatment condition (AITA, EAI, BAU), and the other factor was the instructional setting (resource room, inclusive classroom).

The notion of this research design was a 3×2 design with 6 cells written as:

AITA (A) in resource room (1):	NR	O ₁₂₃₄	X _{A1}	O ₁₂₃₄
AITA (A) in inclusive classroom (2):	NR	O ₁₂₃₄	X _{A2}	O ₁₂₃₄
EAI (B) in resource room (1):	NR	O ₁₂₃₄	X _{B1}	O ₁₂₃₄
EAI (B) in inclusive classroom (2):	NR	O ₁₂₃₄	X _{B2}	O ₁₂₃₄
BAU (C) in resource room (1):	NR	O ₁₂₃₄	C ₁	O ₁₂₃₄
BAU (C) in inclusive classroom (2):	NR	O ₁₂₃₄	C ₂	O ₁₂₃₄

As Shadish and colleagues (2002) described, X_B served as “gold-standard”, which already has a track record showing its effectiveness against a control group proven by Bottge and colleagues. X_A, serving as a new “innovative treatment”, allowed to answer the casual question, “What is the effect of the innovation compared with that would have happened if units had received the standard treatment?” (Shadish et al., 2002, p. 259). A control group allowed this study to contrast results for a control group with those for two treatment groups, which provided ability to compare effectiveness of the different treatments groups. In addition, a pretest and posttest design enabled to assess within-

group change or improvement in addition to adjust for pre-existing differences before the study. Furthermore, the study used four different tests to accurately measure student math achievements including two researcher-developed tests and two standardized tests.

Materials and Intervention Procedures

Description of BAU

Teachers assigned to the BAU condition followed their regular math curriculum, which was aligned with CCSS-M (2010) and modified by their districts. According to participating teachers' self-reports, lesson plans, instructional materials, and classroom observation records from the researcher, the BAU curriculum addressed most of the math standards taught with the EAI and AITA curriculum.

On one day of the geometry unit in BAU classroom, the math teacher introduced lesson objectives as student friendly version (e.g., I can statement) in the beginning of the class: *I can accurately draw circles using a compass (7.G.2)*; and *I can demonstrate my knowledge of 2D geometry by doing my best on the quiz (7.G)*. Students were asked to write the objectives in their math journal. The math teacher provided a whole group instruction and demonstrated to find diameter and radius and to draw circles using rulers and compass. The teacher related the activity to the textbook (e.g., glossary page) during the whole group instruction and discussion. After the teacher instruction, students were asked to draw circles with radius of 1 inch and 2 inches. The teacher walked around to check students' understanding. After checking students' work, the teacher assigned an activity with drawing artistic figures using circles with radius of 1 inch (see Figure 3). The teacher explained they could color after drawing the figures. After allowing a few

minutes, the teacher went over step-by-step procedural instruction to complete the activity.

3/18/16

Circle Art

- 1) Construct a circle with the center A and a radius of about 1 inch.
- 2) Without changing the width of your compass, place the compass on any point on the circle you constructed and then construct another circle.
- 3) Place the compass point on a point of intersection of the two circles and then construct another circle. An intersection is the point at which two or more lines or arcs intersect or cross.
- 4) Repeat this process until no new circles can be constructed.
- 5) Connect the points of the circles' intersections with each other.
- 6) Now use your imagination and create a colorful piece of art.

Rubric

Items looking for:	Points possible:	Points earned:
Circles about 1" (within ¼")	10	
Correct number of circles	5	
Points at the intersections	5	
Connected the points	5	
Neatness	5	
Color scheme is either:	10	
4) Analogous		
5) Monochromatic		
6) Complementary		

TOTAL POINTS EARNED _____

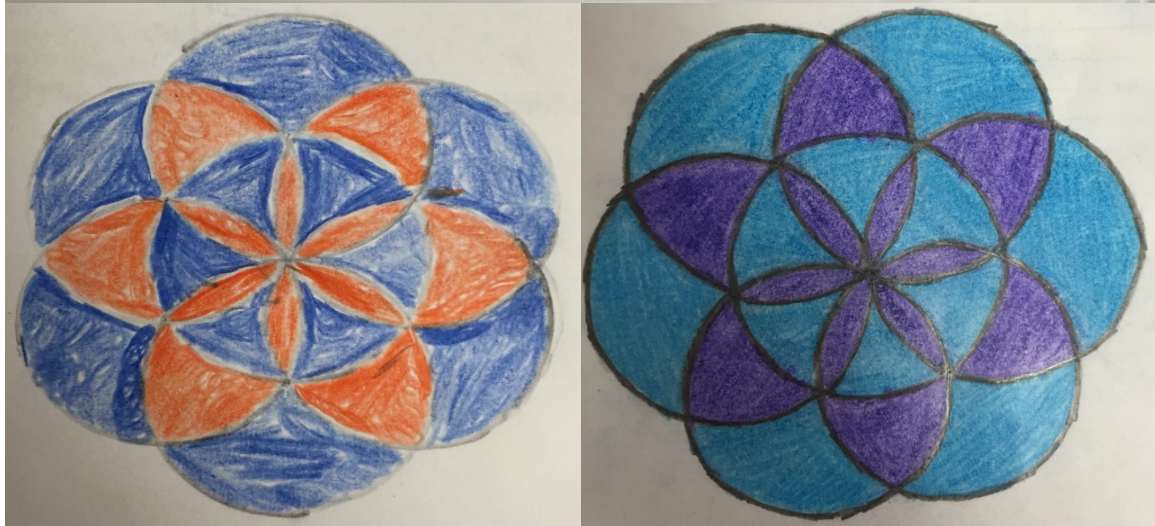


Figure 3. BAU Student Work Sample 1: Circle Art direction and rubric (Top); and samples from two BAU students (Bottom).

Another instructional example of BAU lesson was a project-based learning approach. The lesson objective was that *I can draw a playground model to scale (7.G.1)*, and the activity was designing a playground using the concepts they have previously

learned including measurement, dimension, and scale. In the beginning of the class, students started a warm-up activity with worksheet. The special education teacher led the warm-up activity and checked students' responses on the worksheet. The special education teacher had one student to come to the board and share the answers and provided a feedback with detailed procedural explanations. After the warm-up activity, the math teacher distributed a worksheet (see Figure 4). When the math teacher gave instruction of the activity, the teacher also explained the concept of scale. The math teacher asked students how they could think of calculating scale comparing a real size of playground to a small size drawn on a letter-size piece of paper. The math teacher taught how to convert between drawing scales using procedural instruction approach. Then, students were asked to draw the following playground equipments with a scale of one fourth inch on paper equal to 8 feet in the real world: a merry-go-round in the exact center of the paper, a see-saw 136 feet directly north of the merry-go-round, a slide 80 feet southwest of the see-saw, a swing set 152 feet directly east of the slide, a picnic table 208 feet directly south of the swing set, and a basketball 184 feet directly northwest of the picnic table. Students used the scale to determine the number of inches apart for each piece of equipment on their drawing. Throughout the activity, the math teacher and special education teacher walked around to check with individual students.

During many BAU lessons, teachers used direct instruction, modeling, individual work, and group work as instructional methods. Teaching and learning activities consisted of warm-up questions on basic skills or to review concepts that were taught in the previous lessons, completing worksheets or teacher-made packets, and using hands-

on materials or interactive technologies (e.g., *SmartBoard*). Class periods were typically 60 minutes over an average of 40 instructional days.

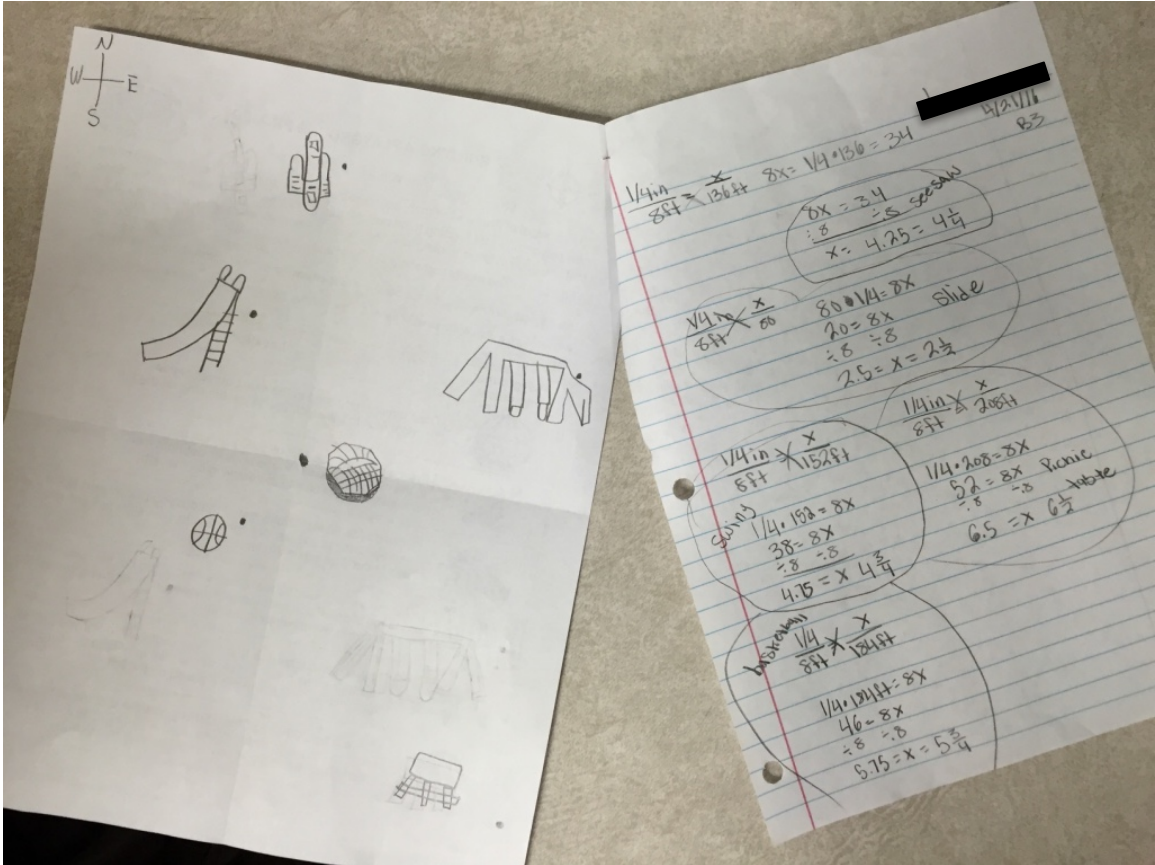


Figure 4. BAU Student Work Sample 2: Designing a Playground

Description of EAI

The EAI curriculum in this study included two units: *Fraction of the Cost* (FOC) and *Hovercraft* (HOV). FOC was a video-based anchored problem lesson, and HOV was a hands-on, project-based lesson. Based on CCSS-M (2010), the two units of EAI curriculum focus on Ratios and Proportional Relationships, Number System, and Geometry. In this study, the average number of instructional days for the EAI group to complete FOC unit and HOV unit were 9.5 days and 28.5 days, respectively.

Fraction of the Cost (FOC). FOC was a video-based, problem-solving unit with an 8-minute video story and contextualized problems. The video story showed that three teenagers trying to build a skateboard ramp with specific conditions given by an adult in the movie. Then, the teenagers explored a schematic plan of a skateboard ramp, determined the materials needed to build the ramp, and discussed the budget to purchase building materials. Examples of the instructional activities in the unit lessons include (a) converting feet to inches, (b) reading a tape measure, (c) building a virtual skateboard ramp on computer, (d) determining the most efficient way to build the ramp with limited budget, and (e) calculating total costs including sales taxes. To complete the unit, students worked in cooperative groups, interacted with the video story multiple times to obtain relative information to solve the anchored problems, and reflected and discuss their problem-solving work.

Hovercraft (HOV). HOV was a hands-on project unit with contextualized problems. It required the participating students to apply the skills they had learned from FOC unit, such as measurement skills, budget planning skills, and calculating sales taxes. In addition, the students were asked to visualize objects from multiple views and construct multi-view drawings. For example, the students were first introduced to the concepts and principles underlying the creation of multi-view drawings with different size and shapes of a rollover hovercraft cages. Then, they constructed their own multi-view hovercraft models and built scale models out of straws. The students also needed to fill out material order forms to build a full-size models out of PVC pipes by calculating unit cost, total cost, and sales taxes. At the end of the unit, students attached their own

hovercraft models on a hovercraft made out of plywood and powered by a leaf blower and took turns riding them through the hallways of their school.

Description of AITA

The AITA curriculum included FOC unit used in the EAI condition to ensure that students had the foundation skills they needed for the next two instructional units. FOC unit took average 10 instructional days for 60-min class period. Then, *Flatland* (FL) and *3D-Hovercraft* (3D-HC) were followed (see Appendix A for sample AITA lesson plans). Based on CCSS-M (2010), those two units were developed focusing on Ratios and Proportional Relationships, Number System, and Geometry. After the initial curriculum was first developed, a middle school math teacher and a university faculty who both previously worked with EAI curriculum reviewed and provided feedback. The curriculum, then, was updated and implemented as a pilot study in two alternative high school classrooms. The pilot study, which was presented at a national conference, showed that the developed AITA curriculum improved math skills of 21 at-risk high school students (Choo & Bottge, 2016). In the current study, the average instructional days to complete FL unit and 3D-HC unit were 9.5 days and 19.5 days for 60-min class, respectively.

Flatland (FL). FL unit was a series of video-based instruction and anchored problems with the use of three-dimensional drawing software (*SketchUp*). The video story introduced geometry concepts including three-dimension, and the participating teachers provided explicit instruction on the math concepts with worksheet for students to practice procedural concepts of geometry standards. When problems were given to students, they needed to watch the video again until they obtain specific embedded

information to solve the problems. The goals of this unit were for students to understand geometric terms, to apply geometric concepts with the anchored problems, and to construct drawings that require dimensioning skills.

The unit began with a 30-minute movie called “*Flatland*” (Flat World Productions, LLC., 2007). The story was based on the 1884 science fiction novella *Flatland: A Romance of Many Dimensions* written by Edwin A. Abbott. Main characters of the movie were two-dimensional figure (e.g., square) and three-dimensional shape (e.g., sphere), and they explored the concept of dimension throughout the movie. At the end of the movie, the students were asked to: (a) draw Flatland figures (polygon) in *SketchUp* and describe what happens as the number of side increases (e.g., perimeter, area, apothem); (b) draw 3 different cubes and compare their surface areas and volumes (1 in, 2 in, & 3 in); and (c) make their own flat car (i.e., two dimensional) first and then make it three dimensional to be 3D-printable. When the problems were shown after the video, students needed to identify relevant information that was embedded in the video anchor (e.g., drawing a two-dimensional car design and using a three-dimensional tool to draw a line on the z-axis).

This unit focused on two specific areas: Geometry and Dimension. Geometry lessons included warm-up questions, direct instruction approach to teach geometric concepts, and solving geometric problems related to the video story. Students learned how to identify irregular polygons and regular polygons, how to calculate perimeter and area with two-dimensional figures, and how to calculate volume and surface area with three-dimensional shapes. In the dimension lessons, the students used a computer-aided drawing program (*SketchUp*) to draw geometric figures they had learned in geometry

lessons. Dimension lessons included instruction modules to demonstrate basic dimensioning skills. The students learned how to identify and use a specific drawing tool for each dimension, how to explain the procedures for dimensioning mechanical drawings, and how to construct dimensions on an engineering drawing. The dimension lessons also included introductory level instruction to operate 3D printers. Once the students completed their 3D model using *SketchUp*, students used a 3D printing software to preview their 3D models and printed their final 3D products out of 3D printers.

3D-Hovercraft. The project-based unit, 3D-HC, was developed based on the contents of *Hovercraft* (HOV) from the EAI curriculum. The main objective of 3D-HC unit was for students to apply the skills they have learned in FL unit (Geometric Construction and Dimensioning Skills). To solve the 3D-HC problems, students were required to use their previously learned geometric and dimensioning skills to plan, draw, and construct a three-dimensional rollover cage for a hovercraft then print out their three-dimensional hovercraft models with 3D printers. Upon completion of their 3D-printed hovercraft models, students attached their models on a battery-operated toy hovercraft (e.g., *4M Hover Racer Science Kit*) and raced each other. Unlike HOV from the EAI curriculum, however, 3D-HC unit included a computer-aided drawing software (*SketchUp*) to draw hovercraft models as three-dimensional figures and to make the hovercraft models out of 3D printers. More specifically, 3D-HC lessons in AITA focused on drawing three-dimensional hovercraft models on all three x-, y-, and z-axes while HOV lessons in EAI consisted of constructing two-dimensional hand-drawing designs on graph papers. As this unit focused on dimensioning skills and measurement skills, the lesson plans consisted of teaching one-, two-, and three-dimensioning skills and

measurement skills using tools on *SketchUp*. Table 1 below shows how each drawing tool in *SketchUp* can be taught for specific secondary math standards (CCSS-M, 2010).

Table 1

Alignment of SketchUp Tools with Math Skills

Focus Areas	<i>SketchUp</i> Tools	Math Skills
One-dimension	<i>Line</i>	Experiment with transformations in the plane (G.CO.1) Use coordinates to prove simple geometric theorems algebraically (G.GPE.6)
	<i>Arc</i>	Find arc lengths and areas of sectors of circles (G.C.5) Experiment with transformations in the plane (G.CO.1)
Two-dimension	<i>Polygon</i>	Use coordinates to prove simple geometric theorems algebraically (G.GPE.7)
	<i>Circle</i>	Understand and apply theorems about circles (G.C.1, G.C.2, G.C.3, & G.C.4) Experiment with transformations in the plane (G.CO.1)
Three-dimension	<i>Push/Pull</i>	Identify the shapes of two-dimensional cross-sections of three-dimensional objects, and identify three-dimensional objects generated by rotations of two-dimensional objects (G.GMD.4)
Measurement	<i>Tape Measure</i>	Explain volume formulas and use them to solve problems (G.GMD.1)
	<i>Navigation</i>	Identify the shapes of two-dimensional cross-sections of three-dimensional objects, and identify three-dimensional objects generated by rotations of two-dimensional objects (G.GMD.4)
	<i>Move</i>	Experiment with transformations in the plane (G.CO.2, G.CO.4, & G.CO.5) Understand congruence in terms of rigid motions (G.CO.6 & G.CO.7)
	<i>Rotate</i>	Experiment with transformations in the plane (G.CO.2, G.CO.4, & G.CO.5) Understand congruence in terms of rigid motions (G.CO.6 & G.CO.7)

The students also constructed larger sized hovercrafts using PVC pipes like HOV unit from the EAI curriculum. They were required to produce a list of materials, to calculate unit price and sales tax, and to build the full size hovercraft models. On the final day of the unit, the students attached their full size hovercraft models to the hovercraft base provided by the researcher and took turns riding on them up and down the hallways of the schools. The hovercraft was operated with an electric leaf blower to lift it off of the floor by blowing air through holes in a plastic sheet fastened to the bottom of the base.

Academic Measures

Two criterion-referenced tests (Problem-Solving Test [PS] and Spatial Thinking Ability Test [STAT]) and two norm-referenced tests (Math Problem-Solving and Data Interpretation [ITBS-PS] and Math Computation [ITBS-C]) were used to measure math performance in this study. The tests were administered over three consecutive days right before and after the instructional treatment period. The researcher independently scored each test, and a second rater who had scoring experience in large-scale studies also independently scored 20% of the pretests and posttests across the treatment groups.

Problem-Solving Test (PS). The PS consisted of 12 questions with 10 open response questions and two multiple-choice questions. Each question had possible one point or two points with a total of 20 possible points (partial point available). PS was developed to assess the concepts of Measurement and Data, Number and Operations, and Ratios and Proportional Relationships based on the CCSS-M (Bottge, Ma, Gassaway, Toland et al., 2014; Bottge et al., 2015). For example, the test items asked students to calculate 10% of a bank statement balance, to find a length of a toothpick when the endpoints of ruler were not positioned at zero inches, and to determine a total cost of

materials needed to build a tree house. Internal reliability estimates were .90 at pretest and .94 at posttest.

Spatial Thinking Ability Test (STAT). STAT (Association of American Geographers, 2006) consisted 16 multiple-choice questions and performance tasks. STAT was developed to assess students' problem-solving skills in reading a map, determining a location based on given information, and differentiating among spatial data types (Lee & Bednarz, 2009, 2012) closely aligned with Geometry based on CCSS-M. For example, the test items asked students to visually navigate a road map using verbal information, to mentally visualize a 3D image based on 2D information, and to identify real-life examples based on picture examples of zero dimension, one dimension, or two dimension. Internal reliability estimates were .80 at pretest and .88 at posttest.

Standardized tests. The study used two standardized math achievement subtests from the *Iowa Tests of Basic Skills*, Form C, Level 12 (University of Iowa, 2008): *Math Problem-Solving and Data Interpretation* (ITBS-PS); and *Math Computation* (ITBS-C). The ITBS-PS consisted of 28 multiple-choice questions to assess students' problem-solving skills. For example, 12 questions were word problems, and four questions asked students to interpret data displays to solve the problems. Other questions included using multiple steps and interpreting graphs, charts, or tables. Internal reliability estimates were .89 at pretest and .93 at posttest.

The ITBS-C consisted of 30 multiple-choice questions to assess students' computation skills in four basic operations (addition, subtraction, multiplication, division) with whole numbers, fractions, and decimals. Out of nine addition questions, there were 2 for whole numbers, 4 for fractions, and 3 for decimals. Out of nine subtraction questions,

2 were for whole number, 4 were for fractions, and 3 for decimals. Out of eight multiplication questions, 3 were for whole number, 2 for fractions, and 3 for decimals. Out of four division questions, 3 were for whole number and 1 for decimals. There was no division problem for fractions. Internal reliability estimates were .89 at pretest and .93 at posttest.

Professional Development

The researcher, who had several years of teaching experience with the EAI curriculum, provided professional development for the participating teachers. Test administration procedures and a manual were provided to all participating teachers across the treatment groups. For teachers assigned with the AITA curriculum, the author conducted a 16-hour training for two days to demonstrate the computer-aided drafting software with the AITA curriculum. The AITA teachers had opportunities to learn the lesson plans, to build their own hovercraft rollover cages out of 3D printers and a toy hovercraft kit, and to construct a full-size model out of PVC pipes. Portions of the training instruction were available for AITA teachers to review during the study period. Teachers assigned with the EAI curriculum had one-year of teaching experience with the EAI curriculum from the previous large-scale studies (Bottge, Ma, Gassaway, Toland et al., 2014; Bottge et al., 2015). The researcher provided a 4-hour training to review the EAI curriculum.

Classroom Observations

The researcher, who had been trained and had previous observation experiences with large-scale studies, conducted a total of 19 whole-class period observations (6 in BAU, 7 in EAI, and 6 in AITA). Observation data included demographic information for

each classroom (e.g., school, teacher, number of students), amount of instructional time, and student engagement level across the treatment conditions. For EAI and AITA groups, the researcher evaluated level of treatment fidelity for the alignment to the lesson plans. For BAU group, the researcher used *Microsoft Word* to describe instructional activities to evaluate the content alignment to the treatment group. A second observer, who was a doctoral student with EAI research experience, was trained by the researcher and conducted four observations (1 in AITA, 2 in EAI, and 1 in BAU), which accounted for 21.1% of the total. Interobserver agreements were 98%, 99%, and 98% (AITA, EAI, and BAU, respectively).

Data Collection and Analysis Procedures

Data Collection

After collecting study materials from the participating schools, the researcher entered all data into *Microsoft Excel* spreadsheet, which served as the database. First, the researcher assigned a school ID and student ID for each student without identifying student names or school names. Student characteristics were then entered as following: age as interval data (12, 13, 14, 15), gender as nominal data (Male, Female), ethnicity as nominal data (Caucasian, African American, Hispanic, Asian), and disability status as nominal data (With for students with a disability, Without for students without a disability). Classroom factor data were entered as following: treatment condition as nominal data (1 for AITA, 0 for non-AITA; 1 for EAI, 0 for non-EAI); and types of classroom setting as nominal data (1 for resource room, 0 for inclusive classroom). Pretest and posttest measures were entered next. For PS, the researcher manually scored individual tests and entered the total scores of each student. For STAT, ITBS-PS, and

ITBS-C, the researcher entered individual responses for each item and then used an *Excel* formula to automatically score those multiple-choice measures. For example, a student's response for STAT question 1 was "D". The researcher entered "D" in a cell (AO2). All 16 responses from cell AO2 to cell BD2 were entered. In the scoring cell (BE2), a formula was entered to score the 16 responses as following: =IF(AO2="D", 1, IF(AO2<>"D", 0)). The Excel presents "1" as a correct answer in the scoring cell (BE2). Using same formula, all 16 items from cell BE2 to cell BT2 were scored. In the total score cell (BU2), a formula was entered to calculate a total score of STAT as following: =SUM(BE2:BT2). A total score was appeared for STAT of the student. Interrater agreement was 96% on PS, 100% on STAT, 100% on ITBS-PS, and 100% on ITBS-C.

Data Analysis Procedure

A two-level hierarchical linear model ([HLM], Raudenbush & Bryk, 2002) was used to examine the differential effects of three treatment conditions on each math measures. This model was equivalent to Analysis of Variance (ANCOVA) factorial design (treatment by setting) with data hierarchy. Without looking at the classroom level, this was a traditional factorial ANCOVA design. With the presence of the classroom level even though it was empty, however, the data hierarchy was taken into account. In addition, the model provided a baseline to which other models were compared and useful preliminary information about the amount of variances that laid within and between classrooms. In addition, it provided information about the reliability of the level-2 sample mean as an estimate of the true population mean (Raudenbush & Bryk, 2002).

In this study, two-level HLM was most appropriate to address the data hierarchy of students nested within classrooms. The two-level HLM evaluated the math

performance of students on each of the outcome measures controlling for pretest scores, independent variables (treatment condition, setting, interaction between treatment condition and setting), and student variables (age, gender, ethnicity, and disability status). This analysis employed a full information maximum likelihood estimation method, which used all available data except those missing on primary outcome measures.

The Level 1 model was situated at the student level and included all the control variables together with the pretest and posttest scores. Using the PS test as an example with PS_PRE as the pretest score and PS_POST as the posttest score, the Level 1 model was:

$$PS_POST_{ij} = \beta_{0j} + \beta_{1j}*(PS_PRE_{ij}) + \beta_{2j}*(AITA_{ij}) + \beta_{3j}*(EAI_{ij}) + \beta_{4j}*(Setting_{ij}) + \beta_{5j}*(AITA \times Setting_{ij}) + \beta_{6j}*(EAI \times Setting_{ij}) + \beta_{7j}*(AGE_{ij}) + \beta_{8j}*(GENDER_{ij}) + \beta_{9j}*(ETHNICITY_{ij}) + \beta_{10j}*(DISABILITY_{ij}) + r_{ij}$$

where PS_POST_{ij} was the PS score after the treatment (posttest) for student i in classroom j , PS_PRE_{ij} was the PS score before the treatment (pretest) for the same student, and r_{ij} was an error term unique to each student, assuming $r_{ij} \sim N(0, \sigma^2)$. The average PS score of students was presented by β_{0j} for classroom j adjusted for student characteristics and the PS pretest score, and β_{1j} was the regression coefficient for the PS score before the treatment (pretest).

The independent variables were AITA, EAI, setting, interaction between AITA and setting, and interaction between EAI and setting indicated with $AITA_{ij}$, EAI_{ij} , $SETTING_{ij}$, $AITA \times SETTING_{ij}$, and $EAI \times SETTING_{ij}$, respectively. β_{2j} was the regression

coefficient of the AITA condition for the j th classroom; β_{3j} was the regression coefficient of the EAI condition for the j th classroom; β_{4j} was the regression coefficient of the classroom setting for the j th classroom; β_{5j} was the regression coefficient of the interaction between the AITA condition and the classroom setting for the j th classroom; and β_{6j} was the regression coefficient of the interaction between the EAI condition and the classroom setting for the j th classroom.

Student characteristics were age, gender, ethnicity, and disability status indicated with AGE_{ij} , $GENDER_{ij}$, $ETHNICITY_{ij}$, and $DISABILITY_{ij}$ as control variables. β_{7j} was the regression coefficient associated with age for the j th classroom; β_{8j} was the regression coefficient associated with gender for the j th classroom; β_{9j} was the regression coefficient associated with ethnicity for the j th classroom; and β_{10j} was the regression coefficient associated with disability status for the j th classroom.

The Level 2 model was situated at the classroom level without any variables. This level served to take data hierarchy into the model. The Level 2 model was:

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

$$\beta_{1j} = \gamma_{10}$$

$$\beta_{2j} = \gamma_{20}$$

$$\beta_{3j} = \gamma_{30}$$

$$\beta_{4j} = \gamma_{40}$$

$$\beta_{5j} = \gamma_{50}$$

$$\beta_{6j} = \gamma_{60}$$

$$\beta_{7j} = \gamma_{70}$$

$$\beta_{8j} = \gamma_{80}$$

$$\beta_{8j} = \gamma_{90}$$

$$\beta_{10j} = \gamma_{100}$$

where γ_{00} was the average PS posttest score for classroom j ; and u_{0j} was the error term unique for each classroom, assuming $u_{0j} \sim N(0, \tau_{\pi}^2)$. All statistical significance tests were performed at the alpha level of .05, .01, and .001. Hedge's g was used as an effect size (ES) measure.

The interaction between the scores before treatment (pretest) and study variables can often be an issue in experimental designs (Shadish et al., 2002). In order to examine this interaction, the researcher first set the coefficient of the pretest variable that represents the effect of pretest on posttest as random at the classroom level. If this effect does not have statistically significant variance across classrooms, the slope of pretest onto posttest scores is the same across classrooms, implying that the pretest-posttest slope is not moderated by treatment. Next, if this effect does have statistically significant variance across classrooms, the treatment condition is used to model the variation in the effect of pretest on posttest. If the treatment condition is statistically significant, then the pretest-posttest slope is moderated by the study variable(s). The researcher performed this procedure on all outcome measures separately. All measures showed statistically significant variation in the relationship of pretest and posttest at the classroom level. However, the study variables were not statistically significant in any of the cases. The researcher concluded that there was no concern about the interaction between any of the study variables and pretest scores.

Ethical Considerations

Recruitment Process

To recruit participating schools, the researcher sent out emails with brief description of the study to district offices or school principals. For those who responded with their willingness to participate in the study, the researcher either visited the school to present the study details or sent it via e-mail. District approval letters or support letters from principals for this study were received.

Informed Consent Process

Participating teachers sent out parental (or guardian) permission form prior to the first date of the research with a brief description including the purposes and benefits of the study. The researcher visited each classroom and explained the purpose of the research and how the research would look like to all participating students. Students were asked to complete an assent form to show their willingness to participate in this study. Both parents (or guardians) and students were notified that it was voluntary to be a part of the research and they could opt out of the research at any time they wish. Any part of the study was not attempted to start until this informed consent process was completed.

No Harm to Participants

Any activities of this study that students participated in had no more risk of harm than the learning activities in typical middle school math classrooms. In some instances, students might experience mild anxiety in completing the math tests or daily activities. If that happened, the teacher would tell students that they would not have to finish the tests. The instructional activities would be continued on the following day. However, such incident was not reported.

Anonymity and Confidentiality

All research records were anonymous, and all participants' confidentiality was secured. The researcher-generated student ID and school ID numbers were used for research purpose only and not able to identify students' names or schools. All the obtained documents were stored in a locked cabinet, and only the researcher and other designated researcher (e.g., advisor, secondary scorer) had access to the documents. However, under some circumstances, authorized people, including a court and university, may review the documents for safety and research purposes for the future. The researcher will continue to retain the signed documents (e.g., signed consents/assents) and IRB records for at least six years after the study closure.

IRB Approval

The Institutional Review Board (IRB) used a full review process to review this study in Fall 2015. IRB approval for this study was received before the study was taken place in Spring 2016 (see Appendix B).

CHAPTER 4. RESULTS

Descriptive Information

Students Demographics

A summary of the student demographics data in this study is reported in Table 2. Numbers and percents of occurrence in the table provide overview of middle school students participated in this study.

The participating students were from six middle schools located in central Kentucky. Out of 90 students, 33 students (36.7%) were taught with the Anchored Instruction with Technology Applications (AITA) curriculum, 24 students (26.7%) were taught with the Enhanced Anchored Instruction (EAI) curriculum, and 33 students (36.7%) were taught with the Business as Usual (BAU) curriculum. The instructional setting was evenly divided across the treatment condition. Out of 67 students placed in the seventh grade inclusive math classroom, 25 students (37%) were in AITA, 17 students (25%) were in EAI, and 25 students (37%) were in BAU. Out of 23 students placed in the eighth grade resource room, 8 students (35%) were in AITA, 7 (30%) students were in EAI, and 8 students (35%) were placed in BAU.

All the participating students' age range was from 12 to 15. More than half of the participating students were 13 years old (48 students, 53.3%). Age 14 consisted of 32% (29 students), age 12 consisted of 12.2% (11 students), and age 15 consisted of 2.2% (2 students). Student gender was almost evenly divided across the treatment groups (49 male students, 54.4%; 41 female students, 45.6%). In addition, in all three groups, the majority student cases included in the study were Caucasian (75 students, 83.3%) and 15 non-Caucasian (16.7%) consisting of African American (7 students, 7.8%), Hispanic (6

students, 6.7%), and Asian (2 students, 2.2%). A Kruskal Wallis test indicated no statistically significant group difference in setting, age, gender, and ethnicity.

There were more SWD (52 students, 57.8%) than SWOD (38 students, 42.2%) across the treatment conditions. Out of 52 SWD, 19 were in AITA condition, 13 were in EAI condition, and 20 were in BAU condition (57.6%, 54.2%, and 60.6%, respectively). A Kruskal Wallis test revealed that there was a significant group difference in disability status, $\chi^2(2) = 8.02, p = .02$. All the student demographic data were included in the HLM analyses as student variables at Level 1.

Descriptive Statistics

Descriptive statistics of student math achievement pretest and posttest scores are reported in Table 3. Average scores, standard deviations, and number of students who completed each test are reported. The original data sets for this study included 90 students. Some students did not complete either pretests or posttests of PS or STAT. Test occasions only for both pretests and posttests completed were included in the data analysis. The two-level HLMs excluded any missing data when analyzing the data. After deletion of cases due to missing data, 96.7% of PS cases (87 students), 100% of STAT cases (90 students), 95.6% of ITBS-PS cases (86 students), and 100% of ITBS-C cases (90 students) were included in the study.

The average scores of all math achievement tests were improved from pretests to posttests across the treatment conditions. On average, all participating students across the treatment condition increased 1.77 on PS, 1.29 on STAT, 1.29 on ITBS-PS, and 2.16 on ITBS-C.

Table 2

Demographic Characteristics of Participants

		BAU (<i>n</i> = 33)		EAI (<i>n</i> = 24)		AITA (<i>n</i> = 33)		χ^2 (2, <i>N</i> = 90)	<i>p</i>
		<i>n</i>	%	<i>n</i>	%	<i>n</i>	%		
Age								2.80 ^a	.25
	12	3	9.1	5	20.8	3	9.1		
	13	17	51.5	13	54.2	18	54.5		
	14	12	36.4	6	25.0	11	33.3		
	15	1	3.0	0	-	1	3.0		
Gender								3.99 ^a	.14
	Male	21	63.6	9	37.5	19	57.6		
	Female	12	36.4	15	62.5	14	42.4		
Race								.25 ^a	.88
	Caucasian	28	84.8	19	79.2	28	84.8		
	African American	2	6.1	4	16.7	1	3.0		
	Latino	2	6.1	0	-	4	12.1		
	Asian	1	3.0	1	4.2	0	-		
Disability								8.02 ^a	.02
	SWOD	13	39.4	11	45.8	14	42.4		
	SWD	20	60.6	13	54.2	19	57.6		
Setting								.22 ^a	.90
	Resource	8	24.2	7	29.2	8	24.2		
	Inclusive	25	75.8	17	70.8	25	75.8		

Note. BAU = Business as Usual; EAI = Enhanced Anchored Instruction; AITA = Anchored Instruction with Technology Applications; SWOD = Students without Disabilities; SWD = Students with Disabilities.

^aKruskal Wallis Test.

Table 3

Descriptive Statistics of Pretest and Posttest

Group Variables	Outcomes	Pretest			Posttest		
		<i>M</i>	<i>SD</i>	<i>n</i>	<i>M</i>	<i>SD</i>	<i>n</i>
BAU	PS	9.47	5.49	30	9.53	5.76	30
	STAT	4.52	2.11	33	5.21	2.89	33
	ITBS-PS	12.10	4.34	30	12.73	3.38	30
	ITBS-C	11.88	5.71	33	14.09	5.58	33
EAI	PS	13.25	5.75	24	15.79	5.20	24
	STAT	6.58	2.60	24	7.50	2.40	24
	ITBS-PS	16.00	5.96	24	17.42	5.29	24
	ITBS-C	18.96	6.27	24	20.83	5.91	24
AITA	PS	13.73	6.04	33	16.48	4.27	33
	STAT	6.00	2.68	33	8.15	2.03	33
	ITBS-PS	16.41	5.73	32	18.22	4.57	32
	ITBS-C	18.79	6.79	33	21.09	5.51	33
Resource Room	PS	7.09	5.95	23	9.87	6.62	23
	STAT	4.26	2.51	23	6.13	3.40	23
	ITBS-PS	10.43	4.94	23	12.26	4.82	23
	ITBS-C	12.00	5.30	23	13.87	7.11	23
Inclusive Classroom	PS	13.94	4.97	64	15.34	5.01	64
	STAT	6.07	2.46	67	7.16	2.50	67
	ITBS-PS	16.38	5.05	63	17.48	4.36	63
	ITBS-C	17.78	7.02	67	20.03	5.51	67
SWD	PS	9.45	6.18	40	11.48	6.29	40
	STAT	5.00	2.49	42	6.33	3.17	42
	ITBS-PS	12.40	5.04	40	13.65	4.71	40
	ITBS-C	13.12	6.15	42	15.83	6.72	42
SWOD	PS	14.40	4.92	47	15.96	4.82	47
	STAT	6.15	2.58	48	7.40	2.30	48
	ITBS-PS	16.87	5.37	46	18.20	4.32	46
	ITBS-C	19.08	6.67	48	20.75	5.41	48
Total	PS	12.13	6.03	87	13.90	5.95	87
	STAT	5.61	2.59	90	6.90	2.78	90
	ITBS-PS	14.79	5.65	86	16.08	5.03	86
	ITBS-C	16.30	7.06	90	18.46	6.51	90

Note. BAU = Business as Usual; EAI = Enhanced Anchored Instruction; AITA= Anchored Instruction with Technology Applications; SWD = Students with Disabilities; SWOD = Students without Disabilities; PS = Problem Solving Test; STAT = Spatial Thinking Ability Test; ITBS-PS = Math Problem Solving and Data Interpretation, The Iowa Tests of Basic Skills, Form C, Level 12 (University of Iowa, 2008, pp. 53-61); ITBS-C = Math Computation, The Iowa Tests of Basic Skills, Form C, Level 12 (University of Iowa, 2008, pp. 63-66).

Research Findings

Partitions of Variances

The main purpose of estimating the null model in HLM analysis was to assess the degree of between group variance in the dependent variable by partitioning variance into its within and between components (Raudenbush & Bryk, 2002). The null model was used to determine the intraclass correlations (ICC's) and reliability estimates of the Level-1 intercept (β_0) for PS, STAT, ITBS-PS, and ITBS-C. This information is reported in Table 4.

Table 4

Partitions of Variances

Outcome	HLM Models	Variances			
		ICC	RE	δ^2	τ
PS ($n = 87$)	Null	.57	.94	19.13**	25.69**
	Full			8.64	0.00
STAT ($n = 90$)	Null	.38	.88	5.56**	3.42**
	Full			3.96	0.00
ITBS-PS ($n = 86$)	Null	.54	.93	13.52**	15.72**
	Full			9.12	0.00
ITBS-C ($n = 90$)	Null	.54	.93	23.78**	27.69**
	Full			17.72	0.00

Note. ICC = Intraclass Correlation; RE = Reliability Estimate; δ^2 = Student level (within-group) variance; τ = Classroom level (between-group) variance.

** $p < .01$

The ICC shows the total portion of variance across the treatment condition. The ICC's in this study were .57 (PS), .38 (STAT), .54 (ITBS-PS), and .54 (ITBS-C). Thus, the models indicate that 57% of the variance for PS was at the classroom level, whereas

43% of the variance was at the student level; 38% at the classroom level and 62% at the student level for STAT; and 54% at the classroom level and 46% at the student level for both ITBS-PS and ITBS-C.

The reliability estimate represents the proportion of variance at the student level to observed parameter variance. According to Snijders and Bosker (1999), reliability estimates of .70 or higher are considered high and indicate that the intercepts are reliable predictors. The reliability estimates in this study were .94 for PS, .88 for STAT, and .93 for both ITBS-PS and ITBS-C. It is concluded that the intercepts in the study models were reliable in their ability to discriminate the average student math performance at the classroom level.

Findings Related to Research Hypotheses

Four two-level HLM analyses were conducted to examine the data for PS, STAT, ITBS-PS, and ITBS-C. The full model was used to examine each of the research hypotheses with math achievement test scores. Table 5 provides the final HLM results directly relevant to the research hypotheses. Overall, AITA students scored significantly higher than BAU students and/or EAI students on three of the four math achievement measures, and students in inclusive classroom scored significantly higher than those in resource room on two of the four measures. In addition, AITA students in the resource room scored significantly higher than those in other settings and treatment conditions (interaction between the treatment condition and the setting) on one of the four measures. Any of student variables did not have any significant difference on any measures.

Table 5

HLM Results

Outcomes	Parameter	Est.	SE	ES	R ²
PS (<i>n</i> = 87)	Intercept, γ_{00}	12.35 ^{***}	1.17	0.50	.81
	Pretest, γ_{10}	0.66 ^{***}	0.07	0.10	
	AITA, γ_{20}	2.68 ^{**}	0.97	0.41	
	EAI, γ_{30}	2.82 [*]	1.07	0.43	
	Setting, γ_{40}	-3.58 [*]	1.46	-0.54	
	AITA×Setting, γ_{50}	5.48 ^{**}	1.86	0.83	
	EAI×Setting, γ_{60}	3.04	1.86	0.46	
	Age, γ_{70}	-0.05	0.54	-0.01	
	Ethnicity, γ_{80}	0.34	0.92	0.05	
	Gender, γ_{90}	-0.57	0.75	-0.46	
	Disability, γ_{100}	-0.05	0.98	-0.04	
STAT (<i>n</i> = 90)	Intercept, γ_{00}	5.50 ^{***}	0.77	0.47	.56
	Pretest, γ_{10}	0.53 ^{***}	0.09	0.17	
	AITA, γ_{20}	1.17 ⁺	0.64	0.38	
	EAI, γ_{30}	1.04	0.72	0.34	
	Setting, γ_{40}	-1.02	0.93	-0.33	
	AITA×Setting, γ_{50}	3.68 ^{**}	1.23	1.20	
	EAI×Setting, γ_{60}	0.83	1.25	0.27	
	Age, γ_{70}	-0.59	0.36	-0.19	
	Ethnicity, γ_{80}	0.37	0.60	0.12	
	Gender, γ_{90}	0.83	0.49	0.27	
	Disability, γ_{100}	-0.42	0.63	-0.14	
ITBS-PS (<i>n</i> = 86)	Intercept, γ_{00}	15.43 ^{***}	1.19	0.74	.69
	Pretest, γ_{10}	0.47 ^{***}	0.08	0.08	
	AITA, γ_{20}	2.30 [*]	1.05	0.41	
	EAI, γ_{30}	3.37 ^{**}	1.12	0.60	
	Setting, γ_{40}	-1.79	1.45	-0.32	
	AITA×Setting, γ_{50}	2.80	1.19	0.50	
	EAI×Setting, γ_{60}	-1.70	1.95	-0.30	
	Age, γ_{70}	-0.25	0.57	-0.05	
	Ethnicity, γ_{80}	-0.52	0.93	-0.09	
	Gender, γ_{90}	0.63	0.77	0.11	
	Disability, γ_{100}	-1.49	1.00	-0.27	
ITBS-C (<i>n</i> = 90)	Intercept, γ_{00}	15.45 ^{***}	1.62	0.56	.66
	Pretest, γ_{10}	0.45 ^{***}	0.08	0.06	
	AITA, γ_{20}	2.97 [*]	1.40	0.41	
	EAI, γ_{30}	2.84	1.59	0.40	
	Setting, γ_{40}	-5.89 ^{**}	1.95	-0.82	
	AITA×Setting, γ_{50}	5.01	2.60	0.70	
	EAI×Setting, γ_{60}	2.95	2.65	0.41	
	Age, γ_{70}	-1.17	0.77	-0.16	
	Ethnicity, γ_{80}	1.81	1.26	0.25	
	Gender, γ_{90}	0.16	1.03	0.02	
	Disability, γ_{100}	0.85	1.36	0.12	

Note. Est. = Coefficient Estimate; SE = Standard Error; ES = Effect Size; R² = Estimated proportion of overall variance in outcome scores explained by the model.

* $p < .05$, ** $p < .01$, *** $p < .001$

⁺ $p = .07$

Table 5 also provides measures of the adequacy of the HLMs by means of R^2 estimates. In this study, R^2 estimates for HLMs that demonstrated statistically significant treatment effects were .81 in PS HLM, .56 in STAT HLM, .69 in ITBS-PS HLM, and .66 in ITBS-C HLM. The results suggest that approximately 81% of the variance in PS, 56% of the variance in STAT, 69% in ITBS-PS, and 66% of the variance in ITBS-C scores were accounted for by the study models. It is confirmed that each HLM model highly captured variance in posttest score based on Gaur and Gaur's (2006) standard.

Research hypothesis 1: There are statistically significant differences between pretest and posttest scores of students taught with the AITA curriculum compared to the BAU curriculum and/or EAI curriculum on math achievement tests of middle school SWD and SWOD.

The HLM results showed that the AITA curriculum was a positive significant predictor of PS, ITBS-PS, and ITBS-C and a marginal predictor for STAT. Results of the PS test for the AITA treatment was statistically significant, $\gamma_{20} = 2.68$, $p = .007$ with the moderate effect sizes ($[ES] = .41$). Statistically significant treatment effects were also found to the advantage of the AITA curriculum on both standardized posttests with moderate effect sizes, ITBS-PS ($\gamma_{20} = 2.30$, $p = .032$, $ES = .41$) and ITBS-C ($\gamma_{20} = 2.97$, $p = .037$, $ES = .41$). No statistically significant difference was found on STAT, $\gamma_{20} = 1.17$, $p = .071$ with moderate effect size of .38). However, this should be interpreted with some caution given the relatively small number in the data set ($N = 90$). It can be considered that students taught with the AITA curriculum had marginally larger gains on STAT than those with the BAU and/or EAI curriculum.

Additional finding from the HLM results was that the regression coefficients of the EAI curriculum were positive and statistically significant for PS ($\gamma_{30} = 2.82, p = .010$) and ITBS-PS ($\gamma_{30} = 3.37, p = .004$) with moderate effect size of .43 and .41, respectively. The regression coefficients of the EAI curriculum were not statistically significant for STAT or ITBS-C, although the coefficients were positive.

Research hypothesis 2: There are statistically significant differences between pretest and posttest scores of students who received math instruction in the resource room and inclusive classroom on math achievement tests of middle school SWD and SWOD.

The HLM results showed that there were statistically significant effects only in PS and ITBS-C posttest scores by the setting across the treatment conditions. The resource room setting was a negative significant factor of math achievement for the PS test, $\gamma_{40} = -3.58, p = .017$ with moderate effect size ($ES = -.54$) and ITBS-C, $\gamma_{40} = -5.89, p = .003$ with high effect size ($ES = -.82$). It indicates that students who learned math in inclusive math classrooms scored significantly higher on PS and ITBS-C posttests than those learned math in resource rooms. However, no statistically significant difference was found on STAT or ITBS-PS, although the coefficient estimates were negative.

Research hypothesis 3: There are statistically significant differences between pretest and posttest scores affected by the interaction between the treatment condition and the instructional setting on math achievement tests of middle school SWD and SWOD.

The HLM results showed that there were statistically significant interaction effects only in PS and STAT posttest scores by the treatment condition and the instructional setting. The interaction term was a positive significant factor of math achievement for PS, $\gamma_{50} = 5.48, p = .004$ with high effect size ($ES = .83$) and STAT, $\gamma_{50} =$

3.68, $p = .004$ with high effect size ($ES = 1.20$). It indicates that students taught with the AITA curriculum in resource room scored significantly higher in both PS and STAT than students who taught with the AITA curriculum in inclusive classroom and those taught with other curriculum in any settings. However, no statistically significant interaction effect was found on any standardized tests, although the interaction estimates were positive.

Research hypothesis 4: There are statistically significant differences between pretest and posttest scores based on student age, ethnicity, gender, or disability status on math achievement tests of middle school SWD and SWOD.

The HLM results showed that student characteristics, such as age, ethnicity, gender, and disability status were not significant predictors of the math achievement tests, and the regression coefficients relating student variables were not statistically significant on any of four measures. First, no statistically significant effects of age were found on any math achievement tests. The coefficient estimates (γ_{70}) were $-.05$ on PS ($p = .926$, $ES = -.01$), $-.59$ on STAT ($p = .109$, $ES = -.19$), $-.25$ on ITBS-PS ($p = .656$, $ES = -.05$), and -1.17 on ITBS-C ($p = .129$, $ES = -.16$). Second, no statistically significant effects of ethnicity were found on any math achievement tests. The coefficient estimates (γ_{80}) were $.34$ on PS ($p = .714$, $ES = .05$), $.37$ on STAT ($p = .538$, $ES = .12$), $-.52$ on ITBS-PS ($p = .573$, $ES = -.09$), and 1.81 on ITBS-C ($p = .155$, $ES = .25$). Third, no statistically significant effects of gender were found on any math achievement tests. The coefficient estimates (γ_{90}) were $-.57$ on PS ($p = .456$, $ES = -.46$), $.83$ on STAT ($p = .092$, $ES = .27$), $.63$ on ITBS-PS ($p = .412$, $ES = .11$), and $.16$ on ITBS-C ($p = .876$, $ES = .02$). Fourth, no statistically significant effects of disability status were found on any math

achievement tests. The coefficient estimates (γ_{100}) were -.05 on PS ($p = .961$, ES = - .04), -.42 on STAT ($p = .506$, ES = - .14), -1.49 on ITBS-PS ($p = .142$, ES = - .27), and .85 on ITBS-C ($p = .533$, ES = .12). It indicates that students from different age, ethnicity, or gender groups did not score significantly higher than other groups, and either of SWD or SWOD did not outscore significantly on any math achievement tests.

CHAPTER 5. DISCUSSION

Discussion of the Study

The first goal of this study was to develop a curriculum-based technology tool, called Anchored Instruction with Technology Applications (AITA). Based on pedagogical concepts of Anchored Instruction (AI), AITA attempted to integrate educational technology into the Enhanced Anchored Instruction (EAI) curriculum and to provide education research area with a rigorous evidence of an innovative way to deliver math instruction using technology applications for students with disabilities (SWD). Then, the study investigated the differential effects of AITA compared to EAI as well as Business as Usual (BAU) on problem-solving skills of middle school SWD. The ultimate goal of the study was to explore learning theories that support AITA to become a part of a coherent instruction to improve problem-solving skills of students who struggle with traditional teaching approaches.

As an extension of EAI, AITA was expected to have significant impacts on students' problem-solving skills as suggested by research literature (CTGV, 1990; Bottge, 1999; Bottge et al., 2001; Bottge et al., 2010; Bottge, Ma, Gassaway, Toland et al., 2014; Bottge et al., 2015). Results showed that both EAI and AITA were significantly effective for improving problem-solving skills of SWD and SWOD. It is argued that the results were found to be consistent with the previous EAI studies, because AITA was developed on the same critical features of situated learning theory from which AI originally developed (Bransford et al., 1990, CTGV, 1990, 1997; Gersten & Baker, 1998; Young, 1993). More specifically, AITA utilizes the same instructional approach that EAI situates problems in authentic and meaningful contexts in which students can relate to real-life

problems (Bottge et al., 2002) based on situated learning perspectives (Brown et al., 1989; Lave & Wenger, 1991; Wilson & Myers, 2000), which CTGV (1992) applied in the context of technology-based learning activities for improving problem-solving skills. Using the same concepts of AI from CTGV and EAI, AITA uses video stories that allow students to solve realistic problems in a meaningful context, construct their knowledge with multiple perspectives through collaborative work, and transfer the knowledge into other similar situations. For example, when AITA students designed their own cars in *Flatland* unit, they were required to use dimension, measurement, and other geometry skills that they had previously learned through video-based lessons. Both EAI and AITA students could successfully apply and transfer previously learned skills and knowledge to real-world looking problem situations as measured by two problem-solving tests (PS and ITBS-PS). Thus, the present study not only supports research literatures that the EAI curriculum successfully improved mathematics problem-solving skills, but it also provides an empirical evidence that the use of technology applications combined with the EAI curriculum helped middle school SWD and SWOD to improve mathematics problem-solving skills.

Although EAI significantly improved some students' problem-solving skills, many SWD still struggled in some math areas. The study findings revealed that EAI was effective on general problem-solving skills (PS and ITBS-PS) but not on spatial skills (STAT) or computation skills (ITBS-C). It may be because students were not motivated or engaged in learning math through hands-on applications with the EAI curriculum, or it can be explained by low motivation, limited attention spans, or difficulties in receiving large bodies of information and complex subjects that SWD often have in general (Bobis,

Anderson, Martin, & Way, 2011; Stephenson, Martin, & Linfoot, 2000). On the other hand, AITA was significantly effective for improving all math achievement tests among three treatments including computational skills measured by ITBS-C and geometry skills as measured by STAT. This can be explained by the nature of the AITA curriculum. AITA students first learned foundational geometry and basic computer-aided drawing (CAD) skills in *Flatland* unit using an explicit instructional approach as recommended by Bottge (2001a) and completed an intro-level 3D printing project. In the following unit of *3D-Hovercraft*, students were exposed to a higher-level project that further developed their spatial knowledge in designing, prototyping, and constructing a rollover cage of their hovercraft for racing. Throughout the learning activities in AITA, teachers and students could make connections between technology skills, math content knowledge, and pedagogical approach as recommended by Mishra and Koehler (2006). It is argued that technology applications like CAD software and 3D printers were used effectively with the AITA curriculum where they were integrated with authentic problems. It is also argued that AITA enabled students to become independent learners by allowing them to experience some advantages of in-context apprenticeship training and follow the way experts think and solve problems to understand why, when, and how to use various concepts and strategies to solve complex problems in realistic situations. These findings support extant research that the effective use of educational technology can be highly effective in improving academic achievement of SWD (Blackhurst, 2005b; Bryant et al., 1998; Hasselbring & Glaser, 2000; Lewis, 1998, 2000; Okolo, 1990; Okolo & Diedrich, 2014).

In addition, the study showed a mixed result that both SWD and SWOD taught in inclusive classrooms scored significantly higher on two (PS and ITBS-C) out of four math measures. This finding partially supports research that teaching students in inclusive settings results in higher academic achievement for both SWD and SWOD in some academic skills (Harrington, 1997; McLeskey & Waldron, 2011; Rea, McLaughlin, & Walther-Thomas, 2002). The finding also supports the concern made by Hocutt (1996) that there is no disadvantage of SWOD in learning in classes that also serve SWD. In contrast to this result, another finding of the study that deserves attention was that the AITA curriculum was the most effective when taught in a resource setting compared to other curricula or instructional settings to improve geometric problem-solving skills as measured by PS and STAT. This might be explained by the nature of resource setting that there were fewer students (8 students) in AITA resource room than AITA inclusive classroom (25 students), so the resource teacher could easily enable students to connect technology skills of CAD software and 3D printers with conceptual math skills of the AITA curriculum. The resource teacher had more flexibility to provide technical supports to meet eight individual students' needs with complexed CAD skills compared to two inclusive classroom teachers with 25 students. However, this specific finding cannot be generalized due to small sample size of eight students (8.89%).

Furthermore, the study results also revealed that student characteristics, such as student age, ethnicity, gender, and disability status, did not have any significant effects on math achievement. One interesting result was that the gain scores of SWD were even higher (2.03 points) than SWOD (1.56 points) on PS. However, the descriptive statistics showed that SWD constantly scored lower than SWOD on both pretests and posttests for

all measures. Overall, this finding supports the research concerning of achievement gap between SWD and SWOD in both special education and mathematics education (NCES, 2011, 2013). The finding also aligns closely with previous research that SWD often struggle with mathematics calculation and mathematics problem solving (Bryant et al., 2000; Fuchs & Fuchs, 2002; Gonzalez & Espinel, 2002; Jordan & Hanich, 2000; Krawec, 2014).

Limitations of the Study

There are several limitations of this study that need to be addressed. First, a small sample size can cause a generalization issue for the study. Out of 102 original participating students, 12 students failed to return signed parent consent forms. This resulted in the smaller than expected sample size. Although the effect sizes of the results were shown to be sufficient, a total of 90 participants may have skewed the results in a way that has not to be explained. Especially, there were only eight students (8.89%) of the total population in two out of six participating classrooms. The results with such a small sample size may decrease the possibility of generalization and may not be relevant in other contexts. Second, due to missing data on PS and ITBS-PS, data from three students for PS and four students for ITBS-PS were not included in the analyses. Third, some student-level factors were not included in the study. For example, learning attitude and motivation, self-efficacy in mathematics, or behavioral issues may have an impact on the student achievement results. Fourth, relevant teacher-level variables and school-related factors were not included in the study, such as teaching experience, highest degree of teachers, teacher attitude and self-efficacy, average school social economic status, or

school enrollment. These variables may have impacts on student academic outcomes and would possibly cause different results.

Implications of the Study

Methodological implications. Although the research methods used in the current study were not new, they were combined in ways that had not been done previously. The study used a quasi-experimental 3×2 factorial design combined with multiple treatments and control group with addition of pretest (Shadish et al., 2002). As Shadish and colleagues stated, the use of both pretest and control group provided more validity to the study especially when pretest differences exist. Due to the statistically significant differences on pretest scores on all measures, the selection maturation threat could increase for the groups with higher pretest scores. The research design which included both a pretest and a comparison group allowed the current study to examine this selection-maturation threat to validity.

In addition, the study used more than two independent variables or factors with three different treatments, which produced six different groups or cells. As Shadish and colleagues (2002) argued, this factorial design allowed to test whether a combination of treatments is more effective than one treatment and interaction effects among different independent variables or factors. In order to examine differential effects of three different treatments, two different settings, and interaction effects between treatments and settings, this mixed research design was most appropriate.

This study was also unique regards to the data analysis approach. The HLM used in this study was equivalent to a classic Analysis of Covariance (ANCOVA) model with an exception that the classroom level (Level-2) effects were viewed as random, and group

effect, u_{0j} , was conceived as random rather than fixed (Raudenbush & Bryk, 2002). Four two-level HLMs were used to statistically analyze the data structure where students (Level-1) were nested within classrooms (Level-2) for each math achievement measures. The models tested main effects for the treatment and setting conditions as well as interaction effects between the treatment conditions and setting conditions. Because the treatment was implemented in classroom level, a nested or hierarchical design was used instead of a single-level analysis. In other words, students were nested within classrooms with the treatment administered at the classroom level. However, all variables were specified at Level 1 rather than specified at two different levels, including the classroom variables. Having all variables specified at one level would give the same treatment effects as having variables specified at two levels. Because there were only six cases (participating classrooms) with five classroom-level variables (AITA [γ_{20}], EAI [γ_{30}], Setting [γ_{40}], AITA×Setting [γ_{50}], EAI×Setting [γ_{60}]), it was necessary to ensure sufficient amounts of variances at all levels of the hierarchy in HLMs (Woltman, Feldstain, MacKay, & Rocchi, 2012).

Practical implications. Technology tools and applications are becoming increasingly prevalent in society and have been playing a significant role in the attainment of academic, vocational, and adult life goals of individuals with disabilities (Alper & Raharinirina, 2006; Davies, Stock, & Wehmeyer, 2002; Wehmeyer, Smith, Palmer, & Davies, 2004). In addition, legislations such as the Assistive Technology Act of 2004 (P.L. 108-364) and the Individuals with Disabilities Education Improvement Act of 2004 (P.L. 108-446) mandate the use of technology to be considered as a part of the Individualized Education Program planning process for SWD. However, such technology

should be based on sociocultural contexts in which it is used. If any devices significantly clash with cultural value or cause stigma issues, people with disabilities tend to abandon the devices (Davies et al., 2002; Parette & Scherer, 2004). AITA used multimedia tool to engage students with video lessons first and then moved to solve contextualized problems by using information embedded in a video anchor as an extended form of CTGV's AI and Bottge's EAI. The video anchor was linked to an applied task that required the use of CAD software and 3D printers, which directly immersed students in problem-solving situations through a combination of multimedia and hands-on contexts. All the technology tools and applications used in AITA were commercially available for everyone, thus there would be no stigmatizing effect with the AITA curriculum.

In addition, the study provided a two-day training for AITA teachers to acquire proper knowledge and skills for successful implementation of the AITA curriculum as previous research recommended (Bottge et al., 2009; Mishra & Koehler 2006; Stephenson et al., 2000). Although the findings of this present study showed effectiveness of AITA for improving student math achievement, the results might be different if it was not implemented with fidelity. The AITA curriculum required much from teachers in terms of its complexity and the brevity of time in which the instructional activities are to be mastered. As proposed by Mishra and Koehler (2006), to teach the AITA curriculum effectively, therefore, teachers should not only understand technology, pedagogy, and content knowledge, but they also implement technology within the mathematics concepts and pedagogical strategies so that they can challenge and support students to learn through the use of technology. Furthermore, educators who are interested in teaching the AITA should be adequately trained with the curriculum

frameworks, selected curriculum materials, instructional units and lesson plans, and assessment tools (Bransford et al., 2000; NCTM, 2000).

Suggestions for Future Research

Based on the findings and review of the study, the following suggestions should be considered for the future research. First, future studies should include larger participants in similar studies. Larger sample sizes may increase the power of study test with greater possibility of generalization, particularly the significant differences in the interaction effects between AITA and resource setting.

Second, future studies should use a three-level model to examine teacher-level and school-level variables. A three-level HLM would provide additional explanation of teacher effects on student achievement. It would provide information related to the interaction between different level variables as well.

Third, future studies should incorporate a mixed methods approach with both qualitative and quantitative data. For example, qualitative data such as student and teacher interview or survey would provide additional information with a more balanced view related to the study goals.

Fourth, future studies should compare the treatment effects on the math achievement of SWD who were taught in the resource rooms compared to SWD who were taught in inclusive settings. It would provide direct information related to the instructional setting effect for SWD.

Fifth, future studies should also focus on developing mathematics curriculum with the use of 3D printers and CAD software for different grade levels. A wide variety of activities with technology applications including 3D printers have been attempted to

support academic learning (Sheridan et al., 2013; Sheridan et al., 2014), but efforts to integrate such technology tools into K-12 curriculum are still nascent and underresearched. Application of this study to other grade levels would offer comparative information and expand the ability to generalize findings from the current study.

Conclusion

It is concluded that the integrated technology into the EAI curriculum (AITA) improved math performance with both problem-solving and computation skills of middle school SWD and SWOD. This study argues that middle school students in general tend to learn some math skills better in inclusive setting, but resource setting had a mixed impact on geometry achievement with technology skills for SWD.

The current research study expands previous research by providing an empirical evidence that when technology applications are successfully integrated into rigorous math curriculum and delivered to students by well trained teachers with technological-pedagogical-content knowledge, such curriculum-based technology tools have significant impacts on math performance of middle school SWD and SWOD. The study also provides continuous evidence that the EAI is highly effective in improving problem-solving skills for secondary students as well (Bottge, Ma, Gassaway, Toland et al., 2014; Bottge et al., 2015).

In conclusion, the major focus of the study was on developing a range of individual students' mathematical skills within social and cultural contexts for improving student problem-solving skills through the technology-based intervention process. With anchored instruction perspective, those two different views of individual construction and social interaction do not counteract each other; yet social interaction is used to maximize

the effect of individual construction. As Ernest (1996) stated, “there is a need for constructivism to accommodate the complementarity between individual construction and social interaction” (p. 345), AITA might be one of the first steps to show how well individual learning and social construction can support each other. Overall, this study may encourage our educators in special education and math education, education researchers, and policy makers to pay closer attention to the current trend of technology-based instruction in order to “accelerate, amplify, and expand the impact of effective practice that support student learning, increase community engagement, foster safe and healthy environment, and enable well-rounded educational opportunities” (U.S. Department of Education, 2016. p. 31).

Appendix A: Sample AITA Lesson Plans

AITA

Lesson Plan

FL22

Day Four Lesson Plan

Objectives

- Students apply the basic drawing skills for a project-based activity.
- Students create their own cars.

Materials Needed

- Warm Up
- Computer with SketchUp
- Toy Car Design Kit
- Sample of Toy Car
- Homework:
 - Car Surface Area and Volume Worksheet

Warm Up

What is your dream car or favorite car? Go find an image of a car you will like to make. Make sure to find a profile picture with side view. [Show examples and non-examples of side view of car profile pictures.]

Once students find a profile picture of their favorite cars, have them save the image file on computer with their name and date.

Checking Yesterday's Homework

Check Additional surface area and volume homework from yesterday. Homework key is provided.

Car Design Activity

Today, you are going to design your favorite car. You will make it based on the profile picture you've saved from warm-up activity.

1. Display #3 question: "Make your own flat car first and then make it 3D."
2. After opening SketchUp, students import their profile images into SketchUp. Click "File" and "Import". Once a new window is popped up, make sure to have Format as "All Supported Image Types" and then locate the folder they have saved their file and click to open it. Next, one click on the origin, move the mouse on any point of the origin, and then another click to place the image.
3. Choose a "Tape Measure" tool from the menu. One click on the green axis and move the mouse to the right (do not second click at this point). Once you hover around the

Anchored Instruction with Technology Applications

Flatland Unit

mouse, you will notice the length is change on the right bottom. Type 5" and press enter. Then, a vertical dotted guideline will appear. [*The image of car might be too small or too big. The following step will ensure you have a right size.*] After clicking to select the image, choose a "Scale" tool from the menu. Once you put the mouse on the upper right corner, a box of message will appear (Uniform Scale about Opposite Point). Then, one-click on the right upper corner and move the mouse to re-size the image. In addition, using "Move" tool, make sure to have one side of the car on the green axis and the other side of the car on the dotted guideline. [*This ensures that the length of car to be 5 inches.*]

4. Students will start chasing the outline of the car. Before start drawing, click "View – Face Style" and select "X-ray". This will make the picture semitransparent and easy to trace the car's outline. The main tools you will use are: (1) "Line" tool for straight lines; and (2) "2 Point Arc" tool for curve lines. For "Line" tool, you need to first click on a starting point and then second click on an ending point. For "2 Point Arc" tool, you still need to first click on a starting point and second click on an ending point. Then, you need to move the mouse either left or right to adjust bulge, which makes the line curve. [*In some cases, students can use "Freehand" tool, but encourage not to in order to have better shape.*] Once students complete drawing the car outline, the car body will turn grey inside (i.e., closed shape), and it is their *flat* car.
5. Encourage students to change the views from top to side view until the car becomes *flat* or disappear with horizontal side view. Have a discussion on how to make it 3D. [*In order to make their flat (or 2-dimensional) car 3D, you need to add the 3rd dimension or z-axis.*] Using "Push/Pull" tool, you will make it 3D. After selecting "Push/Pull" tool, click the car and type 1.5 inches and press enter key. Now you have a 3-dimensional car.
6. Now, you need 2 holes for wheels and axles, which will be provided. Using "Circle" tool, draw a circle with radius of $\frac{3}{32}$ inch (or diameter of $\frac{3}{16}$ inch). The ideal location of the circle is 1 inch from front/rear bumper and $\frac{1}{2}$ inch from the bottom. Once they have 2 circles on one side of the car (either left or right), pull the circle all the way to the other side (i.e., 1.5 inches) to make a circular prism (i.e., cylinder) inside of the car for axles.

Wrap Up Question

How can you find surface area and volume of your car?

Homework

Complete Car Surface Area and Volume worksheet

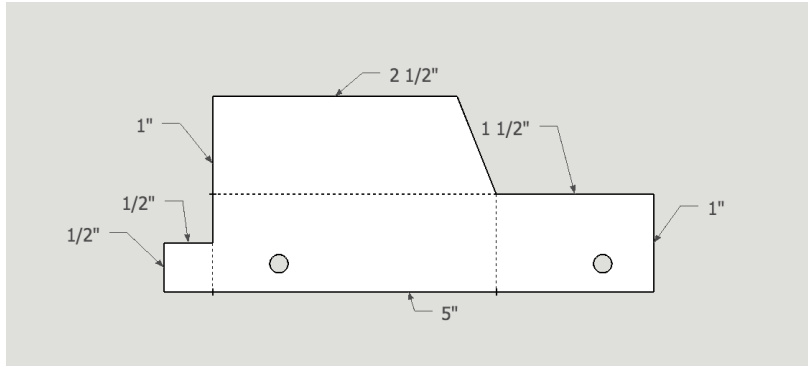
Checklist

Complete the Day 4 Checklist

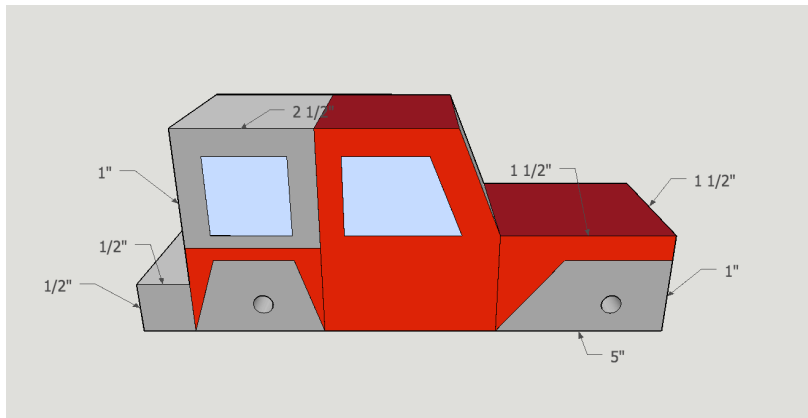
Name: _____ Date: _____

FLATLAND: Car Surface Area and Volume Worksheet

1. Find the area of the side of the following car.



2. Using the area you've calculated in question 1, find the volume of the car. Width of the car is $1\frac{1}{2}$ inches.



Day One Lesson Plan

Objectives

- Students learn to read and build a model from a plan.
- Students draw centerline using 1-dimensional tool in computer-aided drafting software.

Materials Needed

- Computer with SketchUp
- Projection system
- Pre-made Hovercraft .skp file (Large build arounds, Mid build arounds) in CD's
 - 2 sets of Large (A & B)
 - 6 sets of Mid (1 through 6)
- A picture of Hovercraft (Large A) to show/introduce how to build hovercraft
- Hovercraft Building Activity
 - One 3-D printed Hovercraft model (Large A): a building plan is in Teacher CD
 - Six 3-D printed models (Mid #1 - #6): each should have a building plan in Student CD
 - Rulers
 - Stopwatch

Warm Up

Draw the following line segments using a ruler

- 2"
- 1"
- 1/2"
- 1/4"
- 1/8"
- 1/16"

Hovercraft Building Activity

1. Show a picture and SketchUp file of Large A Hovercraft to introduce hovercraft building activity. This picture will show how to read 3D building plan, use "Tape Measure" tool in SketchUp, and build 3D printed hovercraft model.
2. Display one of the hovercraft plans (1/8 size). Using "Orbit" and "Pan" tools, show how to change different views (shortcut keys are also available; Ctrl+1 for Top view, Ctrl+2 for Bottom view, Ctrl+3 for Front view, Ctrl+4 for Back view, Ctrl+5 for Left view, Ctrl+6 for Right view, & Ctrl+7 for Isometric view). Discuss different views of

the hovercraft. Try not to give them too much information, as this activity is designed to be a process of discovery learning.

3. Divide the students into maximum of six groups with 2 to 3 students per group. Then, give each group (1) a container with the 3D printed hovercraft model (2) a ruler, and (3) building plans in CD. [Note: They should not open the container or begin working until all groups have received a container and you tell them to begin.]
4. Let the students know that you are going to time them as they put together their hovercraft model. When they have completed their model, they should sit down and raise their hands. Then, you will give them their time. Although you may not want to do this, the students tend to enjoy the element of competition.
5. When all groups are finished, have them take the models apart and try a new plan. Rotate the groups and give them as many turns as they would like. Each model is different, and some are harder than others. [Note: You may choose to compare the time taken to assemble the first model to the time taken to assemble the second model or even make a chart on the board of their times.]

SketchUp Lesson

You are to demonstrate how to draw center-lined plan of Large A Hovercraft. Make sure students to be able to perform independently and check on their understanding. Repeat any steps if needed.

1. Display Large A Hovercraft plan (e.g., SketchUp file) and the actual model (e.g., 3D printed) that you used in the beginning of the class as an example. Explain that you will show the students how to draw a centerline plan.
2. First, before open a new template of SketchUp, make sure to choose the template as "3D Printing – Inches". Then, using "Rectangle" tool, draw a rectangle with 6-inch length and 4½-inch width. Explain this rectangle is the base of hovercraft. Then, from each corner of the base, draw a vertical line (using "Line" tool" with up/down press key) as the pre-made design indicates specific lengths of each part. Once you draw a line, click to select the line (it should be turned blue) and then click "Tools" from menu bar. Click "Dimensions" and click and drag to display the dimension right next to the original line. A length of the line will be shown.
3. To draw lines on red-axis (x-axis) and/or green-axis (y-axis), press right arrow key for red-axis and left arrow key for green-axis. Make sure to type correct length for each line.
4. To draw a diagonal line, you need to draw a line with specific length another side of the screen. Then, using "Move" and/or "Rotate" tools, adjust the line as the pre-made plan. Explain that no need to draw connectors, since it is a centerline drawing. Connectors will be added later.

Material List of Hovercraft

1. Display Large A Hovercraft plan on screen. Distribute Material List Worksheet A.

2. Based on the Large A Hovercraft plan (e.g., SketchUp design), list each piece of centerlines with same length. [Skip the table of Connector Type at this point.]
3. Show how to best use the 7 ½" layout when drawing centerlines. [Place the longest first and then next longest, and so on.]

*Note: For struggling students, use 7/8" instead of 57/64".

Wrap Up Question

What did you learn today about building and designing a hovercraft model?

Homework

Material List Worksheet A needs to be completed before next class period except connector part. Have students complete the worksheet as homework. Distribute hard copy of Large A Hovercraft plan along with the Material List Worksheet A.

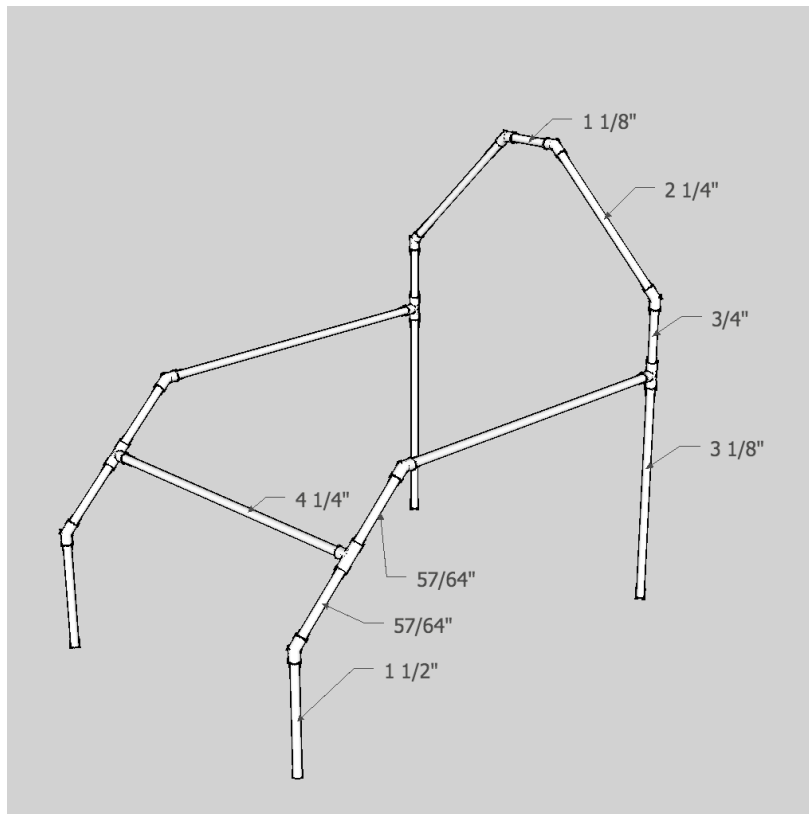
Checklist

Complete the Day 1 Checklist

Name: _____

Date: _____

Hovercraft: Hovercraft Plan Large A (One Eighth)



Appendix B: IRB Approval Forms



Office of Research Integrity
IRB, IACUC, RDRC
315 Kinkead Hall
Lexington, KY 40506-0057
859 257-9428
fax 859 257-8995
www.research.uky.edu/ori/

Initial Review

Approval Ends
January 27, 2017

IRB Number
16-0061-F4S

TO: Sam Choo
Special Education & Rehabilitation Counseling
229 Taylor Ed Bldg, campus 0001
(859) 257-4713

FROM: Chairperson/Vice Chairperson
Non-medical Institutional Review Board (IRB)

SUBJECT: Approval of Protocol Number 16-0061-F4S

DATE: February 24, 2016

On February 19, 2016, the Non-medical Institutional Review Board approved minor revisions requested at the convened meeting on January 29, 2016 for your protocol entitled:

*Developing Technology Applications for Improving the Problem-Solving Skills
of Middle School Students with Learning Disabilities*

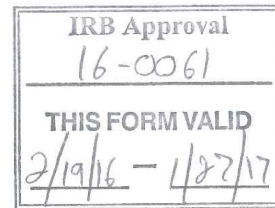
PLEASE NOTE: A copy of the finalized approval letter from Jessamine County Schools should be submitted to ORI prior to beginning research activities in that school system.

Approval is effective from January 29, 2016 until January 27, 2017 and extends to any consent/assent form, cover letter, and/or phone script. If applicable, attached is the IRB approved consent/assent document(s) to be used when enrolling subjects. [Note, subjects can only be enrolled using consent/assent forms which have a valid "IRB Approval" stamp unless special waiver has been obtained from the IRB.] Prior to the end of this period, you will be sent a Continuation Review Report Form which must be completed and returned to the Office of Research Integrity so that the protocol can be reviewed and approved for the next period.

In implementing the research activities, you are responsible for complying with IRB decisions, conditions and requirements. The research procedures should be implemented as approved in the IRB protocol. It is the principal investigator's responsibility to ensure any changes planned for the research are submitted for review and approval by the IRB prior to implementation. Protocol changes made without prior IRB approval to eliminate apparent hazards to the subject(s) should be reported in writing immediately to the IRB. Furthermore, discontinuing a study or completion of a study is considered a change in the protocol's status and therefore the IRB should be promptly notified in writing.

For information describing investigator responsibilities after IRB approval has been obtained, download and read the document "PI Guidance to Responsibilities, Qualifications, Records and Documentation of Human Subjects Research" from the Office of Research Integrity's IRB Survival Handbook web page [<http://www.research.uky.edu/ori/IRB-Survival-Handbook.html#PIresponsibilities>]. Additional information regarding IRB review, federal regulations, and institutional policies may be found through ORI's web site [<http://www.research.uky.edu/ori/>]. If you have questions, need additional information, or would like a paper copy of the above mentioned document, contact the Office of Research Integrity at (859) 257-9428.

Chairperson/Vice Chairperson



Consent to Participate in a Research Study

Developing Technology Applications for Improving the Problem-solving Skills of
Middle School Students with Learning Disabilities

WHY IS YOUR CHILD BEING INVITED TO TAKE PART IN THIS RESEARCH?

Your child is being invited to take part in a research study about the effectiveness of a technology-based teaching method, called *Anchored Instruction with Technology Applications*. The study will attempt to develop the math skills of middle school students, including students with learning disabilities. Your child is being invited to take part in this research study because he/she is attending one of the schools where the principal has agreed to be part of this study. If you give permission for your child to take part in this study, your child will be one of about 100 students in a few public school districts in central Kentucky.

WHO IS DOING THE STUDY?

The person in charge of this study is Samuel Choo, Ph.D. Candidate of University of Kentucky Department of Early Childhood, Special Education and Rehabilitation Counseling. He is being guided in this research by Dr. Brian Bottge, William T. Bryan Endowed Chair in Special Education at University of Kentucky. There may be other people on the research team assisting at different times during the study, and they are affiliated with University of Kentucky.

WHAT IS THE PURPOSE OF THIS STUDY?

The main purpose of this study is to develop and test the effectiveness of an instructional approach called *Anchored Instruction with Technology Applications*, which uses 3D printers and computer software (e.g., *SketchUp*) to improve students' math skills. This study will compare the math achievement of students using a new teaching method to the math achievement of students who are learning math using their usual curriculum. The learning activities and materials have been systematically developed, and all curricula are aligned with the middle school math standards. By doing this study, we hope to learn how to improve instructional approaches in math.

ARE THERE REASONS WHY YOUR CHILD SHOULD NOT TAKE PART IN THIS STUDY?

Students participating in this study will not be exposed to any harm either physically or mentally. All students in your child's classroom are invited to take part in this study, and there is no reason your child should not take part in this study. Your child will receive either the new math instruction or the math instruction he/she would typically receive if your school were not involved in the study.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The research procedures will be conducted in your child's math classroom at the school your child attends. He/she will not need to come to University of Kentucky at any time during the research. This study will last approximately eight to ten weeks.



WHAT WILL YOUR CHILD BE ASKED TO DO?

This research will evaluate three different teaching methods for the purpose of improving students' math skills. Students in some schools will be taught in one of the new ways: *Enhanced Anchored Instruction* (e.g., Multimedia-based instruction with hands-on activities); or the extension of it called *Anchored Instruction with Technology Applications* (e.g., Technology-based instruction with 3D printers and *SketchUp*). Students in the other schools will be taught math in the usual way. Your child's school will be systematically chosen to use the new way(s) or the usual way. Thus, you will not have a choice as to which type of math instruction your child receives.

To measure what students have learned, all participating students, regardless of their group, will be asked to take math tests at the beginning and the end of the study during their regular math instruction. The tests take about 120 minutes. In addition, students will complete a brief attitude survey about learning mathematics. This is expected to take 10 to 20 minutes. If you do not give permission to use the test and survey results, your child will still take the tests and the survey, but we will not use the results for research purposes.

Your child may be photographed and/or videotaped as he/she works on the math curriculum. These tapes/pictures will help researchers get a better understanding about how to teach and learn math. Portions of the tapes/pictures may be used for educational purposes to show parents and educators how students responded to their math curriculum. If you do not give us permission to take pictures and/or to videotape your child, he/she may still participate in all other parts of the study.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

To the best of our knowledge, the learning activities your child will be participating have no more risk of harm than he/she would experience in typical middle school math classrooms. In some cases, students may experience mild anxiety in completing the math tests. If that happens, the teacher will tell your child that he/she will not have to finish the tests.

In addition, to help describe the students involved in the study, researchers may review information in your child's academic records such as age, gender, grades, and other tests' scores. If your child is receiving special education services, researchers will review your child's Individualized Education Plans (IEP's) for progress on annual goals and objectives. Only the researchers will have access to the individual information collected. Students will be referenced by number rather than by name. The research data will be stored on password-protected computers and locked in cabinets at University of Kentucky. Neither your name nor your child's name will appear in any reports of the research.

WILL YOUR CHILD BENEFIT FROM TAKING PART IN THIS STUDY?

There is no guarantee that your child will get any benefit from taking part in this study. However, we do expect that most participating students will improve their math skills. We also expect that most students will improve their attitude toward learning math once they experience the new math curriculum. For those in the control group, students will not get any personal benefit from taking part in this study since they won't experience the new math curriculum.

DOES YOUR CHILD HAVE TO TAKE PART IN THE STUDY?

Your child's participation in this project is voluntary. Regardless of whether you agree your child to be in the research or not, your child will still receive math instruction your child's teacher is using. If permission is not granted, we will not use the information from the tests in our analysis and will not access any of your child's data or video record him/her. Your child may withdraw from the study at any time, and there is no penalty for withdrawing or not participating. The decision to participate or not participate will not affect your child's grades.

IF YOU DON'T WANT YOUR CHILD TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?

If you do not want to take part in the study, your child will still receive math instruction and take the tests. If your child withdraws from participation, we simply will not use the information from your child's tests in our analysis.



WHAT WILL IT COST YOU TO ALLOW YOUR CHILD TO PARTICIPATE?

There are no costs associated with taking part in the study.

WILL YOUR CHILD RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

Your child will not receive any rewards or payment for taking part in the study.

WHO WILL SEE THE INFORMATION THAT YOUR CHILD GIVES?

The study investigators will access the data being collected in your child's classrooms, the academic records, and the video recording. Your child's information will be combined with other participating children's information. When we write about this study to share with other researchers, we will write about this combined information we have gathered. Your child will not be personally identified in these written materials. We may publish the results of this study but we will keep your child's name and other identifying information private. We will make every effort to keep confidential all research records that identify your child to the extent allowed by law. However, there are some circumstances in which we may have to show your child's information to other people. For example, the law may require us to show your child's information to a court, or to tell authorities if your child reports information about a child being abused or if your child poses a danger to himself/herself or someone else. Also, we may be required to show information that identified you and your child to people who need to make sure we have done the research correctly. These would be people from such organizations as University of Kentucky.

CAN YOUR CHILD TAKING PART IN THE STUDY END EARLY?

If you decide to give permission to your child to participate in the study, you still have the right to decide at any time that you no longer want to continue. Your child will not be treated differently if he/she decides to stop taking part in the study.

The individuals conducting the study may need to withdraw your child from the study. This may occur if you are not able to follow the directions they give you.

WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS, CONCERNS, OR COMPLAINTS?

Before you decide whether to allow your child to accept our invitation to take part in this study, please contact the investigator, Samuel Choo, Ph.D. Candidate, at 859-257-7391, and/or his research advisor Dr. Brian Bottge, at 859-257-7908 and ask any questions that might come to your mind now. Later, if you have questions, suggestions, concerns, or complaints about this study, you can still contact the investigator or his advisor. If you have any questions about your child's rights as a volunteer in this research, contact the staff in the Office of Research Integrity at the University of Kentucky between the business hours of 8am and 5pm EST, Mon-Fri. at 859-257-9428 or toll free at 1-866-400-9428.

If you want to give permission to your child to participate, please sign and return one copy of this consent form to the investigator and keep one copy for your records. We request that you keep a copy for your records in order to have the contact information for both the investigator and University of Kentucky Office of Research Integrity as listed above.

WHAT ELSE DO YOU NEED TO KNOW?

There is a possibility that the data collected from your child may be shared with other investigators in the future. If that is the case the data will not contain information that can identify your child unless you give your consent or the UK Institutional Review Board (IRB) approves the research. The IRB is a committee that reviews ethical issues, according to federal, state and local regulations on research with human subjects, to make sure the study complies with these before approval of a research study is issued.



Parent Permission Form

By signing and returning this form to the investigator, I am agreeing to my child's participation in this research project. I understand that this participation will involve the use of my child's pretest and posttest results. I further understand that the additional items listed below are optional, and I have indicated my responses to each.

I give permission for my child to participate in this study. Yes _____ No _____

I give permission for my child to be photographed for research purposes. Yes _____ No _____

I give permission for my child to be videotaped for research purposes. Yes _____ No _____

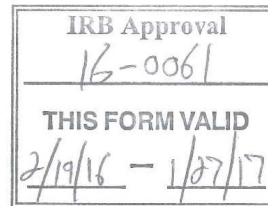
I give permission for the researchers to use segments of the pictures and videotapes for training. Yes _____ No _____

(Child's full name) _____

(Printed Parent/Guardian Name) _____

(Signature of Parent/Guardian) _____

(Date) _____



ASSENT FORM

Developing Technology Applications for Improving the Problem-solving Skills of Middle School Students with Learning Disabilities

You are being invited to participate in a research study being done by Samuel Choo, Ph.D. Candidate and his research advisor, Dr. Brian Bottge from the University of Kentucky. If you agree to participate in this study, you will be one of about 100 students in Kentucky. This study will take place in your math class for about eight to ten weeks.

The purpose of the project is to compare three different ways of teaching and learning math. Students in some school will learn a new math curriculum, while students in other schools will learn the usual math curriculum. Your school will be systematically chosen to use either one of the new ways or the usual way, so you will not have a choice as to which type of math instruction you will receive.

To measure what you have learned, students in all groups of schools will be asked to take math tests at the beginning and at the end of the study during regular school hours. The tests take about 120 minutes. You will also be asked to take a learning attitude survey about math (about 15 minutes). On several occasions, you and your classmates will be video recorded and/or photographed. The videos and pictures will help us understand how you were able to solve the math problems. We may share parts of the tapes with parents and teachers, so they can understand how you learned math. If you don't give us permission to use the video and/or pictures for these purposes, we will edit you out of the video/picture so you are not shown.

Your family will know that you are in the study. If anyone else is given information about you, they will not know your name. A number or initials will be used instead of your name. In addition, researchers may review information in your academic records such as age, gender, grades, and other tests' scores. Your participation in this project is voluntary. If something makes you feel bad while you are in the study, please tell your teacher(s). If you decide at any time not to finish the study, you may stop whenever you want. There is no penalty for not participating. Your grade will not be affected. If you decide not to participate, you will still receive math instruction and you will still take the tests. However, we will not use your test results in our research project.

You can ask Mr. Choo (sam.choo@uky.edu; 859-257-7391) and/or Dr. Bottge (brian.bottge@uky.edu; 859-257-7908) questions any time about anything in this study. You can also ask your parent any questions you might have about this study.



Student Assent Form

Signing this paper means that you have read this or had it read to you, and that you want to be in the study. If you do not want to be in the study, do not sign the paper. Being in the study is up to you, and no one will be mad if you do not sign this paper or even if you change your mind later. You agree that you have been told about this study and why it is being done and what to do.

I agree to be photographed for research purposes. Yes _____ No _____

I agree to be videotaped for research purposes. Yes _____ No _____

I give permission for the researchers to use segments of the pictures and videotapes for training. Yes _____ No _____

(Printed Student Name)

(Signature Student Name)

(Date)

(Researcher Signature)

(Date)

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VITA

Samuel Y. Choo

Department of Early Childhood, Special Education,
and Rehabilitation Counseling
University of Kentucky
Lexington, KY

Education

Ph.D. Department of Early Childhood, Special Education,
2017 and Rehabilitation Counseling
(expected) University of Kentucky, Lexington, KY
Major: Special Education
Emphasis: Assistive/Instructional Technology

M.Ed. Department of Special Education
2008 University of Kansas, Lawrence, KS
Major: High-Incidence (Adaptive) Disabilities

B.A. Department of Special Education
2005 Daegu University, Daegu, South Korea
Major: Secondary Special Education

Certification

2009 **KY Professional Certificate for Teaching Exceptional Children**
Rank I (2014), *Learning and Behavior Disorders (K-12)*

2013 **North Carolina Professional Educator's License**
Standard Professional I, *Special Education: General Curriculum*
Standard Professional I, *Middle Grades Mathematics*

2013 **Assistive Technology Certificate**
University of Kentucky, Lexington, KY

Professional Experiences

2016 **Lead Teacher & Research Consultant**
- Present *Frankfort Independent Schools & Kentucky State University*
Frankfort, KY
Title: *Engaging the Capital City Community in Establishing a STEM+ Pipeline*, Funded by the William R. Kenan Jr. Charitable Trust (\$399,850)

2014 - 2016 **Lead Teacher**
The Learning Center, Fayette County Public Schools, Lexington, KY

2013 - 2014 **Teacher, Special Education & Mathematics**
Spring Lake Middle School, Cumberland County Public Schools, Spring Lake, NC

- 2011 - 2013 **Graduate Research Assistant**
University of Kentucky, Lexington, KY
 Title: *Evaluating the Efficacy of Enhanced Anchored Instruction for Middle School Students with Learning Disabilities in Math*, Funded by the Institute of Education Science (Goal 3), U.S. Department of Education (\$2,330,164), Principal Investigator: Brian A. Bottge, Ed.D.
- 2009 - 2011 **Teacher, Special Education & Mathematics**
 Bondurant Middle School, *Franklin County Public Schools*, Frankfort, KY
- 2008 - 2009 **Para-Professional, Special Education & Mathematics**
 Corden Porter School, *Greater Clark County Public Schools*,
 Jeffersonville, IN

Publications & Presentations

- Choo, S. Y. & Bottge, B. A.** (2017, April). *Developing technology applications with 3D printers for improving the problem-solving skills*. Poster presentation accepted at the 2017 Annual conference of the Council for Exceptional Children, Boston, MA.
- Choo, S. Y. & Bottge, B. A.** (2017, April). *Comparing effects of a math intervention delivered in resource and inclusive classrooms*. Oral presentation accepted at the 2017 Annual conference of the Council for Exceptional Children, Boston, MA.
- Choo, S. Y.** (2016, June). *Makerspaces as a graduation strategy*. Oral presentation at the 2016 Persistence to Graduation Summit of Kentucky Department of Education, Lexington, KY.
- Choo, S. Y. & Bottge, B. A.** (2016, April). *Using 3D printers and computer-aided design software to improve mathematics problem-solving skills*. Oral presentation at the 2016 Annual conference of the Council for Exceptional Children, St. Louis, MO.
- Choo, S. Y.** (2016, March). *Developing technology applications for improving the problem-solving skills of middle school students with learning disabilities: Preliminary report*. Oral presentation at the 2016 Spring Research Conference, University of Kentucky, Lexington, KY.
- Choo, S. Y.** (2016, March). *Curriculum development with 3D printers for improving visual-spatial skills of at-risk high school students*. Oral presentation at the 27th Annual National Youth-At-Risk Conference, Savannah, GA.
- Choo, S. Y.** (2015, November 30). The nexus between teaching and research: What I learned working on an IES grant [Web log post]. Retrieved from <http://ies.ed.gov/blogs/research/post/the-nexus-between-teaching-and-research-what-i-learned-working-on-an-ies-grant>

- Choo, S. Y.** (2015, June). *SketchUp and 3D printers*. Workshop at 2015 Kentucky Department of Education, Digital Symposium, Lexington, KY.
- Bottge, B. A., Toland, M., Gassaway, L., Butler, M., **Choo, S. Y.**, Griffin, A., & Ma, X. (2015). Impact of Enhanced Anchored Instruction in inclusive math classrooms. *Exceptional Children, 81* (2), 158-175. doi:10.1177/0014402914551742
- Hefling, M., Jones, M. E., & **Choo, S. Y.** (2014, November). *Using technology to enhance engaged learning for at-risk students*. Presentation at the 2014 KySTE Fall Training Event: Digital Transformation, Lexington, KY.
- Bottge, B. A., Toland, M. D., Gassaway, L., Butler, M., **Choo, S. Y.**, Griffin, A. K., & Ma, X. (2014, April). *Multilevel analysis of Enhanced Anchored Instruction in coteaching inclusive math classrooms*. Roundtable presentation at the 2014 Annual conference of the American Educational Research Association, Philadelphia, PA.
- Choo, S. Y.** (2014, April). *Community partnerships building a brighter future*. Invited panel discussion at the 2014 Annual meeting of the North Carolina's Electric Cooperatives, Raleigh, NC.
- Choo, S. Y.**, Knight, V. F., & Bausch, M. E. (2013, April). *Using a token economy system via the iPad to increase classroom participation and decrease disruptive behavior of students with ADHD*. Poster presentation at the 2013 Annual conference of the Council for Exceptional Children, San Antonio, TX.
- Bottge, B. A., Butler, M. D., **Choo, S. Y.**, & Gassaway, L. J. (2013, April). *Detecting error patterns and improving fractions computation*. Roundtable presentation at the 2013 Annual conference of the Council for Exceptional Children, San Antonio, TX.
- Hudson, T. M., Knight, V. F., & **Choo, S. Y.** (2013, March). *Evaluating effects of web conferencing software on active student responding in a graduate course*. Oral presentation at the 2013 Annual conference of American Council on Rural Special Education, Orlando, FL.
- Butler, M. D., Griffen, A. K., & **Choo, S. Y.** (2012, November). *Enhanced Anchored Instruction (EAI): Improving math skills of middle school students*. Roundtable presentation at AdvancED Kentucky/UK College of Education Innovation Summit, Lexington, KY.

University Teaching Experiences

Kentucky State University

EDU 203: *Microcomputers and Media in the*, Fall 2016, Spring 2017

University of Kentucky

EDS 514: *Instructional Technology in Special Education*, Summer 2016, Fall 2015, Summer 2015, Spring 2015, Fall 2014, Summer 2012

EDS 459: *Student Teaching in Special Education*, Fall 2014, Fall 2012

EDS 601: *Applied Behavior Analysis*, Summer 2012

Service Experiences

2017, April **Conference Session Chair**

American Educational Research Association (AERA)

Invited to paper session chair titled, *Embodying, Personalizing and Rendering Mathematics Using Technology* at the 2017 AERA Annual Meeting in San Antonio, TX

2017, January **Teacher Trainer**

University of Kentucky, Lexington, KY

Trained in-service teachers for *Developing Enhanced Assessment Tools for Capturing Students' Procedural Skills and Conceptual Understanding in Math*, funded by the Institute of Education Science (Goal 5)

2017, January **Teacher Evaluator**

Franklin County Public School, Frankfort, KY

Served as an evaluator for the district's teacher of the year

2016, June **Proposal Reviewer**

- Present

American Educational Research Association

Division of Learning and Instructions (C), Section of Mathematics (1c); & Section of Technology-Based Environments (3b)

2013, June **Proposal Reviewer**

- Present

Council for Exceptional Children (CEC)

Technology and Media Division

2016, October **Proposal Reviewer**

International Society for Technology in Education

Focus topic: Digital age teaching & learning

2016, May **Nominations and Election Committee**

Council for Exceptional Children (CEC)

Technology and Media Division

2015, June **Proposal Reviewer**

National Youth-At-Risk Center

2011, August **Children and Youth Action Network Coordinator**

- 2013, May

Student Council for Exceptional Children (SCEC)

University of Kentucky, Lexington, KY

Awards

- 2015, August **Arvle and Ellen Turner Thacker Research Fund**
University of Kentucky, Lexington, KY
Received \$ 1,000 doctoral dissertation grant
Title: Developing technology applications for improving the problem-solving skills
- 2015, August **Barbara J. Edwards Special Education Fellowship**
University of Kentucky, Lexington, KY
Received \$1,500 scholarship
- 2013, November **Bright Ideas Grant**
North Carolina's Electric Cooperatives, Raleigh, NC
Received \$1,500 grant
Title: Project-based learning for students with math learning disabilities
- 2013, August **Dermontti F. & Regina M. Dawson Graduate Fellowship in Education**
University of Kentucky, Lexington, KY
Received \$1,000 scholarship
- 2011, August **Sarah Geurin Graduate Scholarsip**
University of Kentucky, Lexington, KY
Received \$1,500 scholarship
- 2011, August **Shirley C. Endowed Graduate Fellowship for Teachers**
University of Kentucky, Lexington, KY
Received \$150 scholarship
- 2006, August **The Speyer Special Education Scholarship**
University of Kansas, Lawrence, KS
Received \$1,500 scholarship
- 1999, March **Daegu University Student Scholarship**
Daegu University, Daegu, South Korea
Received full scholarship

Professional Affiliations

Council for Exceptional Children

Division of Technology and Media

American Educational Research Association

Division of Learning and Instruction

Section of Mathematics & Section of Technology-Based Environments

(Updated on April 17, 2017)