Student-Centered Worked Example Videos: A Multi-Phase Mixed Methods Intervention Study for Students Designated as English Language Learners

by

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ABSTRACT

This study investigates the impact and experiences of students designated as English Language Learners (ELLs) as they engage with student-centered worked example videos (WEVs). Students from two southwestern high schools collaborated and provided their experiences as they watched WEVs and worked through four slope calculation problems. Although high school ELLs are placed in appropriate mathematics classes, the WEVs they engage with, by design, do not consider their diverse educational needs, one of which is the amount of cognitive load experienced when watching the videos. Through this Multi-Phase Mixed Methods study, I begin to understand inclusive design practices for WEVs, in which ELLs will not experience cognitive over-load, and as a result, will receive the needed remediation and/or instruction and develop concept proficiency through active learning as they engage with the videos. The research finds that specific design principles, closed captioning, conversational narration, and music, reduce cognitive load and provide ELLs a familiar and safe space from which to engage with mathematical content.

DEDICATION

This dissertation is dedicated to my madre, Irvia Iris, por quererme de gratis. Gracias por todo el apoyo atra vez de los años. To my son Angel, you have pushed me to grow as a person and as a father. Thank you for your courage to be who you are and choosing me to be part of your life. To my partner, Doctora Ana Isabel Terminel Iberri, thank you for always pushing me to grow and holding me accountable when necessary. Thank you for choosing to create this reality with me day after day. To Margarita for believing in me and helping me push through the system that tried to convince me I did not belong. Estamos aquí y seguiremos aquí.

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CHAPTER 1

INTRODUCTION

As populations in the United States continue to grow, Spanish speaking students designated as English Language Learners (ELLs) are quickly becoming the largest minority group served by public schools across the nation (Kohler & Lazarín, 2007). The term ELL refers to "students who have immigrated to the US or may have been born in the US but raised in a home in which the primary language was a language other than English" (Jimenez-Silva & Olson, 2012, p. 1). According to reports, the ELL population in the United States grew more than 50% from 1996 to 2006 (Batalova et al., 2007), and is expected to continue growing with the continuous political chaos in South and Central America, causing thousands of migrants to flee deadly living conditions as a result of proxy wars and political interference in foreign governments by the United States (Galeano & Belfrage, 1997). As migrants continue to migrate north for better living conditions, population demographics continue to shift.

With the immediate and projected increase of ELLs in public schools and current alarmingly below average academic achievement statistics (Riera & De Lira, 2021), secondary education mathematics teachers are quickly finding themselves ill prepared to address the diverse needs of their students. Since language is such a crucial aspect of achieving mathematics proficiency in public education spaces (Cummins & Cameron, 1994; Moschkovich, 2007), secondary mathematics teachers face a unique challenge as they not only teach mathematics content, but also must contend with the struggle of their students learning English at the same time. Many teachers find themselves lacking the skills and strategies necessary for supporting ELLs in the classroom (Jimenez-silva et al., 2016).

Increasing pressure from legislation and Structured English Immersion programs, students are not given the adequate supports necessary as they work towards English proficiency.

Shifts in education reform continue to shift pedagogy in the classroom. As Common Core is being implemented into curriculums across the nation since 2010, students and educators have felt the challenges of increased demand on students being able to verbally communicate individual proficiency, requirements for use of technology, and required group work (Bostic & Matney, 2014). As technology integration requirements take hold, students find themselves relying on outside resources, such as Khan academy and YouTube videos, for explanations and help in the absence of resources not available at many public schools (Dreon et al., 2011). As useful as these outside resources can be for the general student population, ELLs once again find themselves at a disadvantage as language barriers persist. The implementation of outside resources for instruction and/or remediation must consider the diverse needs of ELLs. As an educator I implicate myself in this process. As a student that was designated ELL in public education, I see myself in the students I serve who continue to struggle with lack of structural support.

Purpose of the Study

The purpose of the study is to examine the various experiences of students as they engage with worked-example videos (WEVs) as well as the effectiveness of such videos in supplementing instruction in a public high school mathematics classroom. Specifically, videos designed to address the cognitive challenges faced by ELLs in the mathematics classroom when using these videos to remediate difficult concepts. In education, students experience this on varying levels. ELLs however, as they struggle to also master the English language in the mathematics classroom, experience a higher level of cognitive load (Van Merrï Enboer & Sweller, 2005). An intervention in the form of experimental videos which implement two strategies proven to decrease cognitive load in students. Those two strategies are closed captions and a conversational tone in narration.

I employ a mixed-methods multi-phase design, experimentally testing the impact of current worked-example video, versus student-centered worked-example videos, developed with varying frameworks from theories of multimedia learning. This mixed-methods study looks to provide insight into the following questions:

1. How and why are students engaging with worked-example videos?
2. How do students' Mathematics performance change before and after watching a Worked Example Video?
3. What are the specific experiences of students designated as English Language Learners as they watch worked-example videos as part of their mathematics learning process?
4. How effective are newly designed illustrated Worked Example Videos for students designated as English Language Learners and other student populations?

The research consists of four phases of data collection and analysis. The first phase will measure student performance on four slope calculation problems, as well as amount of engagement with the educational videos. In this phase, we will also begin to understand the student experience as they engage with videos. The quantitative and qualitative data from the first phase will inform the second phase of qualitative data collection via individual interviews, in which questions will be developed to address the points of engagement with videos and codify reasons and results of student engagement with the videos. Both the quantitative data and qualitative data will be used to guide the member-checking sessions in the third phase of data collection. The collection of data throughout each of the three phases will allow the students and I to make inferences about effectiveness of the worked-example videos used in the study as well as telling a rich story detailing the experiences of these students as they navigate instructional media an educational system not built for their success. A final phase of data analysis will help in creating a full narrative on the student experience and effectiveness of WEVs. In the following chapter, I provide background information and theoretical foundations for the study.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

In secondary education, mathematics is often regarded as one of few subjects that students either "get or don't get". As public education has evolved through the decades, and reforms have changed the landscape and pedagogy in the classroom, there have been several disciplines outside of education as well as non-education related fields that have had a tremendous impact on education. Major education reforms have happened as researchers and scientists begin to look at education from their respective lenses. Technology has always played a very important role in shaping how teaching and learning happens in and outside the classroom. The diverse populations in our public schools have, since the beginning of public schools, impacted not only the process of teaching and learning, but also national school policies governing who can learn and how they are to be taught. In this next section, I will outline the ways in which the field of education, specifically mathematics education, has been shaped by technology, systemic exclusion of Black, Indigenous, and other People of Color (BIPOC), and the field of psychology. I will also extend some of these ideas as I explore how education has impacted technology development, educational policies, and educational interdisciplinary research. Some research around mathematics education revolves around the idea that some of the processes in mathematics depend on the type of knowledge structures required to engage in mathematics.

Knowledge Structures

Worked examples have been used in mathematics education for many years. Although the idea of using an example to teach students the process of solving a problem has been in the foundation of the "I Do, We Do, You Do" pedagogical approach in mathematics instruction for decades (Fisher & Frey, 2013), the worked example as its own methodology of instruction, as well as a remedial method of instruction, began to be incorporated in classrooms across the nation in the late 1900's. Sweller & Cooper (2009) state that, "worked examples are hardly a novelty in education. They are used extensively. Nevertheless, in most mathematics and mathematics-based courses, the emphasis tends to be placed on conventional problem-solving activity rather than on worked examples." (p. 5). Similarly, Greeno (1980), Sweller (1988), and Carroll (1994), all argue that worked examples as an instructional task, while not new, have unfortunately not been the emphasis in most mathematics classrooms. Sweller & Cooper (2009) state that for mathematics instruction and remediation, "far greater use should be made of worked examples and far less use of problem solving" (p. 62). With problem solving being emphasized in the classroom, much of the research around mathematics instruction has focused on important aspects of problem solving.

The idea of using a worked example video to guide students as they solve problems is grounded in the theory of knowledge structures (Greeno, 1980; Kintsch & van Dijk, 1978) as well as the cognitive theory of multimedia learning (Mayer, 1987, 2009a, 2009b). Knowledge structures can vary from discipline to discipline as well as from student to student. The five types of knowledge structures, as explained by Greeno and Mayer, are Process, Comparison, Generalization, Enumeration, and Classification (Greeno et al., 1982; Mayer, 2009a). Each of these five knowledge structures allows instruction to be framed in different ways to allow for active learning.

The first knowledge structure, *Process*, is the structure that allows us to explain a cause-and-effect chain often represented by a flowchart or diagram. Process knowledge structure allows us to explain how some systems work (Cook & Mayer, 1988; Mayer, 2009a). The second knowledge structure, *Comparison*, is used to compare and contrast two or more objects. “Comparison structures can be represented as matrices and consist of comparisons among two or more elements along several dimensions” (Mayer, 2009a). The third, *Generalization*, is used to describe main ideas and support those main ideas with supporting details. Often, generalization knowledge structure is used in history when describing main events in history and providing causes for such events. “Generalization structures can be represented as a branching tree and consists of a main idea with subordinate supporting details” (Mayer, 2009a). The fourth, *Enumeration*, is commonly used for providing a list of related items. The last, *Classification*, “can be represented as hierarchies and consists of sets and subsets” (Mayer, 2009a). This last structure is often found in the sciences when classifying animals and systems of life.

The process of active learning includes selecting, organizing, and integrating (Mayer, 2009a). The first process, selecting, refers to the process in which a student is selecting which pieces of information are important to the topic or concept being presented. As technology in the classroom increases, and the implementation of different technological strategies has grown as well, the merging of worked example as a method of education and technology was inevitable. As with all knowledge and mental processes, learning is limited by how much information our brains can process, which brings us to Cognitive Load Theory.

Cognitive Load Theory

The current state of mathematics instruction is the result of many changes and reforms in the previous century. Changes to math instruction were driven mostly by mathematicians and researchers that held some prominence within different committees overseeing education. In 1915, Dr. William Heard Kilpatrick, with support from the National Education Association's Commission on the Reorganization of Secondary Education, began to challenge the current state of mathematics. According to Klein (2002), Kilpatrick stated “No longer should the force of tradition shield any subject from scrutiny...In probably no study did this older doctrine of mental discipline find larger scope than in mathematics, in arithmetic to an appreciable extent, more in algebra, and most of all in geometry” (p. 179). Dr. Kilpatrick was setting the stage for mathematics to no longer be protected from criticism and open to scrutiny, critique, and eventually reform.

This began a series of events, formations of associations, and publishing of lengthy reports advocating for varied views on mathematics as a subject and as a tool. “In 1922, Edward L. Thomdike promoted a behavioristic model of mathematical learning incorporating the notions of stimuli and responses. This prompted the pedagogical paradigm of ‘Drill and Practice’” (Bossé & Mathematical, 1995, p.177). “Drill and practice”, now commonly called “drill and kill”, would continue to be the most preferred method of “learning” in public schools across the nation, and still used to this day in many schools. In the years that followed this new shift in pedagogy, reform initiatives began to take hold in the form of new curricula in which the curriculum would take shape and be determined as educators decided what the children needed, and less by the academic subjects (Klein, 2002). The cycle of individual needs for mathematics instruction versus societal needs of mathematics instruction had begun and would swing back and forth several times. Due to decreasing enrollment in Algebra and Geometry in the early 1900’s, progressive education began to retreat.

In the 1950’s, the “New Math” period began. This movement, as explained by Bossé (1995), “the inception of the New Math was the collision between skills instruction and understanding” (p. 180). Followed by the transfer instruction movement in the 1960’s, as reported by Bossé (1995), the movement was supported by findings of Robert Gagné (1980). Learning theory research by Gagné did the following:

> proposed a cumulative learning theory which he claimed could facilitate transfer of knowledge from simple to complex through his learning hierarchy of simple-to-more-complex skills and tasks. Effective learning was viewed as tasks that students could perform which led to tasks that incorporated multiple subordinate tasks (p. 177).

The 1970's brought back the Drill and Practice camp for a short time before researchers began to look for alternative methods from which to analyze mathematics instruction.

Researchers looking for other disciplines from which to research how to improve instruction used cognitive sciences and psychology to offer a deeper understanding into the processes of problem solving and instruction. Gagné (1980) offers the following,

> The attractiveness of developing 'rational thinking' and 'problem solving' as a central goal of education has not only occurred to educators. One finds it being expressed, almost always as if a new thought, by scientists who investigate cognitive processes – psychologists, artificial intelligence researchers, and others. (p. 84)

As other disciplines value the importance of problem solving, new ideas and approaches become available to investigate and decompose effective problem solving in mathematics. Researcher and educator James G. Greeno would provide foundational research and theories that would revolutionize education through the lens of psychology and the cognitive sciences. "Recent developments seem to have added a new dimension to the potential use of ideas from psychology and other cognitive sciences in the analysis and design of instruction" (James G. Greeno, 1980, p.1). By applying principles of cognitive sciences and psychology, researchers like Greeno, Sweller, Gagné, among others, used those similar methods to analyze instructional tasks in the classroom. Gagné (1980) points out that many of the new themes and novel approaches in education "appear to have developed out of some dissatisfaction with school-based education – dissatisfaction with its goals or its methods, or both" (p. 84). As dissatisfaction grew with other methods of instruction, in mathematics primarily transfer method, and problem-solving strategies, researchers began to look through theories of psychology and cognitive sciences.

By taking an interdisciplinary approach, researchers looked to understand how deeper understandings of learning processes could have implications on instruction. Researchers, J. G. Greeno et al., (1982), looking at instruction and problem solving in mathematics wanted to "extend cognitive theory by studying cognitive processes involved in understanding and solving problems used in instruction in mathematics, and to explore implications of these cognitive analyses for the design of instruction" (p. 2). Other researchers, Berger et al. (2013), Frederiksen (1983), and K. W. Lee (1985), also looked to understand those cognitive processes in order to find new methods for instruction and problem solving. Experiments by J. G. Greeno et al. (1982) studied the process of understanding problems, aspects of basic skills needed for specific tasks, and strategic decision-making in finding solutions. Views of problem solving based on information-processing theory were common among researchers. J. G. Greeno et al. (1982) argued that basic skills are necessary, however successful problem solving relies on the ability to learn new schema and successfully integrating new information with previously learned information. Gagné (1980) had previously made this argument, stating that "intellectual skills, usually those learned prior to the presentation of the problem, are directly involved in the activity of problem solving" (p. 87). As researchers continued to investigate instruction and problem solving in mathematics, cognitive theory was extended, and understanding of the cognitive processes necessary in mathematics instruction and problem solving began to shape future implications for the mathematics classroom. Research into these cognitive processes and strategies, as shown by Gagné (1980), affirm that these cognitive strategies and processes are very specific to the tasks in the mathematics classroom, are discoverable, and that they can be learned by the learner.

In using cognitive science to research mathematics instruction for problem solving, James G. Greeno (1980) utilized three theories common in both the cognitive sciences and problem solving; the theory of cognitive procedures, the theory of problem solving, and lastly the theory of semantic schemata used in the process of understanding language. Research by James G. Greeno et al. (1996) explains the move towards uncovering the knowledge-specific methods of problem solving was called the "knowledge revolution within cognitive science" (p. 5). Other researchers, Corte (2000), Putnam & Borko (2000), Tuovinen & Sweller (1999), among others, also note the essential shift in focus as well as the importance in developing the research further. Greeno et. al (1996) also state that, "The relationship between theoretical and practical understanding is one of the important aspects of our science that is currently in transition" (p. 15). With this change in perspective, research on instruction was able to expand beyond discovering successful steps and procedures of problem solving and into discovering knowledge structures and cognitive processes and theories that could be applicable universally for all learners.

With the new approaches from cognitive theory, researchers were able to discover necessary knowledge structures for problem solving in the mathematics classroom. Initial research into problem solving showed that successful problem solving requires knowledge for understanding, knowledge of the varying conditions in a problem, and strategic knowledge for problem solving (Frederiksen, 1984; Greeno et al., 1982; K. W. Lee, 1985; Wearne, D., Hiebert, 1988). A report by Greeno et al. (1982) studying the cognitive processes involved in understanding and solving problems in mathematics, shows that the different types of knowledge necessary for successful problem solving could be acquired by learners from various explicit graphical displays. These displays showed representations of problem formation, variable assignments, and erroneous paths. The visual representation of the problem-solving process is extremely important for the learner. Greeno et al. (1982) state, “the opportunity to examine a trace of problem-solving activity and relate steps in the solution effort to strategic goals provides an unusual situation that encourages reflective learning” (p. 54). As learners view the entire solution process, they develop reasons for each of the solution steps chosen to reach the strategic goal of the problem. This approach to problem-solving develops strategic knowledge and reflective learning as they validate alternate solutions that may differ from their own chosen path. Other research by James G. Greeno et al. (1996) and Sweller et al. (1990), also support this important contribution towards expanding cognitive theory in mathematics problem solving and instruction and early foundations towards worked-examples as a method of instruction. Introduced as metacognition by developmental psychologists Brown (1977) and Wellman (1978), researchers James G. Greeno et al. (1996) describe metacognition as “the capacity to reflect upon one’s own thinking, and thereby to monitor and manage it” (p. 19). It is clear from research that the successful learner can reason and develop solution explanations as well as reason and explanations for erroneous solution paths from a solved example problem. James G. Greeno et al. (1996) confirm in their experiments of students working with various types of problems that “the better students treated the examples quite differently, constructing explanations of solutions in terms of problem goals” (p. 19). This expansion of cognitive theory resulted in changes to mathematics instruction focusing on problem-solving. Learners would be exposed to a variety of solved problems with both correct and incorrect solution paths effectively fostering strategic knowledge and reflective thinking.

As cognitive theory continued to expand, researchers began to experiment with Sweller's (1988) cognitive-load theory in the development of worked examples. Cognitive-load theory refers to the amount of cognitive, or mental, effort being used by a learner in the working memory (Sweller, 1988). In his paper, Sweller argues that different types of instructional approaches impose varying amounts of cognitive load on the learner. Talking about conventional problem solving as a learning device, Sweller (1988) states, "There seems to be no clear evidence that conventional problem solving is an efficient learning device and considerable evidence that it is not. If, as suggested here, conventional problems impose a heavy cognitive load which does not assist in learning, they may be better replaced by nonspecific goal problems or worked examples" (p. 283). Other researchers began to investigate the effectiveness of worked examples as a replacement to conventional problem-solving instructional approaches. Experiments by Pass (1992), Paas, van Merriënboer, & Adam (1994), John Sweller et al. (1990), Tuovinen & Sweller (1999), and others, looked to expand on cognitive theory with cognitive load as the new foundation for research into problem solving instruction. Some research focused on measuring cognitive load, while others focused on worked examples in mathematics instruction. It is important to understand the need to not only understand the role of cognitive load theory in mathematics, but also how researchers can successfully measure cognitive load and how the measurement methods have also had a significant impact on instruction.

Researchers Paas, van Merriënboer, & Adam (1994), focused on two different methods of measurements of cognitive load. They defined cognitive load as follows,

> Cognitive load, a multidimensional construct, represents the load that performing a particular task imposes on the cognitive system. The construct can be conceived to

> consist of causal factors and assessment factors affecting cognitive load and those affected by cognitive load (p. 420)

The two different measurement methods tested were a self-rating-scale of the perceived amount of mental effort and a spectral-analysis technique of the heart rate variability. According to their analysis, the rating-scale was found to be reliable, sensitive, and easy to implement in the classroom, while the heart-rate method was found to be low in reliability, sensitivity, and difficult to implement in a classroom (Paas et al., 1994). Another study by Schmeck et al. (2015) using a subjective cognitive load rating scale speaks to validity and reliability of measuring cognitive load against other methods of measurement. It states, "the effectiveness of the rating scale by showing that the variation in learners' cognitive load ratings depended on variations in task complexity or instructional design" (p. 95). As this study and others by Ayres (2006), Chandler & Sweller (1996), Hadie & Yusoff (2016), amongst others, show the ability to measure cognitive load reliably, research also evolved that allowed researchers to investigate and discover how specific strategies in mathematics instruction and problem solving increased or decreased the cognitive load. As these strategies were developed, researchers took to task to investigate which strategies worked best in decreasing cognitive load.

In previous research, Greeno (1980), argued for three theories as important theoretical foci into cognitive load and how they shape worked examples. These are the theory of cognitive procedures, theory of problem solving, and theory of semantic schemata used in the process of understanding language. As cognitive load gained popularity and validity in education research, understanding these theories became the foundational in incorporating worked examples into mathematics instruction and problem-solving strategies to reduce cognitive load and ensure meaningful concept proficiency. Researchers took to task in unpacking, understanding, and implementing these cognitive theories to effectively employ them through worked examples in the classroom.

Theory of Cognitive Procedures

The first theory, theory of cognitive procedures, looks to explain the processes and procedures necessary for solving problems in specific contexts and the acquisition of procedural knowledge in meaningful ways. Frederiksen (1983), J. Greeno (1980), Larkin et al. (1980), amongst others, argued that different problems would require specific procedures to find a successful solution. This cognitive procedures view emphasizes "having structures of information and processes that recognize and construct patterns of symbols in order to understand concepts" (James G. Greeno et al., 1996, p. 18). From this theoretical perspective, researchers were able to deconstruct necessary processes for meaningful specific knowledge acquisition and specific cognition processes what would be useful across many different domains.

These cognitive processes are activated when tasks are challenging and require cognitive activation. "In mathematics lessons, the level of cognitive challenge is determined primarily by the type of problems selected and the way they are implemented" (Blum et al., 2010). While in theory this seems like an easy task, many times, in the mathematics classroom, tasks are often trivial in nature, often become only routines requiring rote memorization of solution steps, which often does not lead to meaningful learning. To ensure cognitive activation, researchers find that there are three crucial dimensions as follows: cognitively challenging and well-structured learning opportunities; learning support through monitoring of the learning process, individual feedback, and adaptive instruction; and efficient classroom and time management (Blum et al., 2010; Feldon, 2007; Wearne, D., Hiebert, 1988). Research investigating cognitive procedures uncovered that through these three dimensions, the specific cognitive processes necessary for concept proficiency were more effectively activated when compared to traditional theories of knowledge transfer. Within these three dimensions, the process of learning the important mathematical concepts requires that instructional practices focus more on the cognitive aspects of concept proficiency, instead of rote memorization of tasks for problem solving.

This shift in focus to cognitive aspects, and away from rote memorization, required teachers to rethink many of their lessons and strategies for students to achieve concept proficiency. Instruction needed to shift away from Drill and Practice and towards cognitive activation exercises. Some of these different instructional strategies, according to Baumert et al. (2010), included, but were not limited to,

> draw on students' prior knowledge by challenging their beliefs. Cognitive activation may also be prompted by class discussion if a teacher does not simply declare students' answers to be 'right' or 'wrong' but encourages students to evaluate the validity of their solutions for themselves or to try out multiple solution paths (p. 145)

With this shift in instruction, the worked example strategy which by design elicits cognitive activation from students, began to gain theoretical popularity as well as practical popularity in the mathematics classroom.

Theory of Problem Solving

The second theory, theory of problem solving, focuses on the necessary knowledge to be acquired for successful problem solving. Research into this theory allowed researchers to discover three main components of knowledge students must acquire to successfully solve problems dealing with specific concepts in mathematics. As Greeno (1980) found in his research, these three main components of knowledge are, "propositions for inference, perceptual concepts for pattern recognition, and strategic knowledge for planning and setting goals"

(p. 10). These components are consistent with those of other research findings on mathematical knowledge acquisition for successful problem solving (Berger et al., 2013; Greeno et al., 1982; Sweller, 1988).

The first component, propositions for inference, also often compared to prior knowledge, focuses on the ability to make implications based on previous information already known or gathered from the problem. As explained by Greeno (1980)

> Each step in solving the problem consists of an inference in which some new relation or the measure of some additional component is deduced from information that was given or that has previously been inferred. The problem is solved when this chain of inferences reaches the relation or measure that is the goal of the problem. Each of the inferential steps is based on one of the if-then propositions that the student knows. The antecedent condition of the proposition is found in the given information or the diagram, and the consequent relation is added to the problem situation. (p. 4)

When discussing strategies for problem solving, researchers agree that many, if not all, require some sort of previous knowledge which would allow for inferences to be made while problem-solving. Research around problem-solving strategies shows that propositions of inference, or prior knowledge necessary to build new knowledge on, are an important aspect of each of them. Fyfe, Rittle-Johnson, & DeCaro (2012) state, "In particular, learners with low prior knowledge often need substantial instructional support, whereas those with higher prior knowledge do not" (p. 1095). These research findings were also supported by researchers Kalyuga (2007) and Tobias (2009) who's research focused on learner-tailored instruction and constructivist instruction respectively.

The second component, perceptual concepts for pattern recognition, are "usually presented in diagrams, with exercises that emphasize the relevant features needed to identify instances of the concepts" (James G. Greeno, 1980, p. 7). The learning of perceptual concepts, as explained by Adolph & Kretch (2015), "entails an increased ability to extract relevant information from a stimulus array as the result of experience" (p. 127). While mathematics instruction is very visual in nature with symbols and numbers being the primary method of perceptual knowledge acquisition, understanding how perceptual knowledge takes place is crucial in cognitive theory and the development and use of worked examples to decrease cognitive load in mathematics instruction and problem-solving strategies. Perceptual learning, the lifework of influential psychologist Eleanor J. Gibson (1969), explains our ability to take information from what we perceive from the structures of the environment we experience on a daily basis. She goes on to argue that the key to knowledge begins with perception. Using fundamentals of perceptual learning, worked examples provide visual structures from which learners can acquire the perceptual concepts for pattern recognition as well as knowledge necessary for successful problem-solving. Looking to expand upon cognitive theories of learning, Moreno & Mayer (1999), saw the need for research in learning theories as technology continued to shape the classroom. Through their experiments, they would expand on current cognitive principles of learning and how to effectively incorporate them using technology. They also found, through their research, that perceptual learning, specifically with multimedia learning, was most effective with low-experience students. Their research finds that low-experience students, those lacking prior knowledge, benefit most when visual models provide the necessary academic supports.

The third component, strategic knowledge for planning and setting goals, refers to the knowledge required in problem-solving to reach the goal state. As explained by Weber

(2001), echoing research by Greeno, strategic knowledge or "heuristic guidelines that they can use to recall actions that are likely to be useful or to choose which action to apply among several alternatives" (p. 111). Not only understanding the different strategies that are applicable in each problem, but also being able to plan and foresee how to reach the goal by implementing specific actions to go from problem state to end state. As research suggests, strategic knowledge is not simple to acquire. In his study, Schoenfeld (1978) finds that students, do not simply acquire this knowledge on their own, "We cannot expect most students to develop coherent strategies for approaching problems even in narrowly prescribed subject domains, if they are left on their own to do so" (p. 678). As Greeno (1980) stated years later, echoing the same sentiment, strategic knowledge is often not implicitly represented in instruction and relatively indirectly addressed in textbooks. Using frameworks from knowledge structures, worked examples provide a visual process from which students can acquire the necessary strategic knowledge. As some researchers have found, Atkinson et al. (2000), Mayer (1987), Sweller & Cooper (2009), among others, the use of worked examples effectively provides students the opportunity to acquire and become proficiently equipped with strategic knowledge for successful problem-solving. Students can visually experience a successful problem solution step-by-step, creating their own strategic knowledge. As the three knowledge components are addressed using worked examples, the second theory proposed of problem solving suggested by Greeno (1980) adds to the validity, effectiveness, theoretical, and practical support of worked examples in mathematics instruction and as a problem-solving strategy.

Theory of Semantic Schemata

Lastly, the theory of semantic schemata concentrated on the necessary and meaningful knowledge units required for mathematics concept proficiency and successful problem-solving and how that knowledge is represented. As Greeno et al. (1996) point out, "People need organizing schemata to understand and use new information. The richer and more appropriate to the problem these schemata are, the faster and more effectively will people be able to solve the problem" (p. 19). To expand on this theory for problem-solving, research focused on the generalizable features of schemata, how learners acquire the necessary schemata, and how the representation takes shape in working memory, short and long term.

When studying generalizable schema between arithmetic and algebra, researchers Reed, Stebick, Comey, & Carroll (2012) find that "Shared schematic components between arithmetic and algebra word problems create the possibility of transfer between the two types of problems. They also create the possibility of common sources of difficulty" (p. 637). While some schema are domain specific, there are instances where specific schema can be applied across multiple domains. Previous research by Kintsch & Greeno, (1985) found that semantic structures needed for text processing during problem-solving have generalizability across problems in arithmetic, as well as processes of language comprehension during problem-solving. Through experiments, researchers found three categories of schemata generalizable across mathematical domains. These three categories, as detailed by Riley, Greeno, & Heller (1984) are "problem schemata for understanding the various semantic relations … , action schemata for representing the model's knowledge about actions involved in problem solutions, and strategic knowledge for planning solutions to problems" (p. 165). These three categories, while they may contain domain specific schema, are still generalizable over all domains as overarching knowledge units for problem-solving.

As research continued to expand cognitive theory by uncovering the necessary knowledge structures for successful problem-solving, implications on instruction provided an easier transfer of research findings into the everyday classroom strategies used by teachers when teaching problem-solving. As researchers continued to investigate worked examples as an instruction strategy, the benefits of worked examples over traditional problem-solving strategies continued to reveal themselves. Sweller & Cooper (Sweller & Cooper, 1985) researching the effectiveness of worked examples find, "Since schema acquisition requires (a) knowledge of problem states, (b) the operators that can be used when a given problem state has been attained, and (c) the consequences of using particular operators, we might expect schemas to be acquired more directly by a worked example approach as opposed to a conventional, goal-directed problem-solving search approach" (p. 69). Echoing findings by Greeno and other researchers, Sweller finds that worked examples provides a process for schema acquisition for all three types of knowledge needed for successful problem solving: understanding problems, operators/actions available, and consequences/planning towards a solution. Students receiving instruction via worked-examples, can understand the processes necessary for successful problem solving, while simultaneously creating knowledge to add to their prior knowledge of possible operations and actions when problem solving.

The three theories discussed, theory of semantic schemata, theory of problem-solving, and theory of cognitive procedures, all play a role in successful problem-solving. Mathematics instruction which addresses and works within the frameworks provided by these theories provide the necessary educational structures necessary for acquiring problem-solving proficiency. As worked examples are designed using these theoretical frameworks, they not only reduce the cognitive load experienced by learners, but also allow them to acquire the different types of knowledge to become proficient in generalizable schemata transferable over different mathematical domains.

The diagram below, Figure 1, explains how the cognitive theory of multimedia learning uses visual and auditory inputs to facilitate learning through sensory memory, working memory, and long-term memory (Mayer, 2009a).

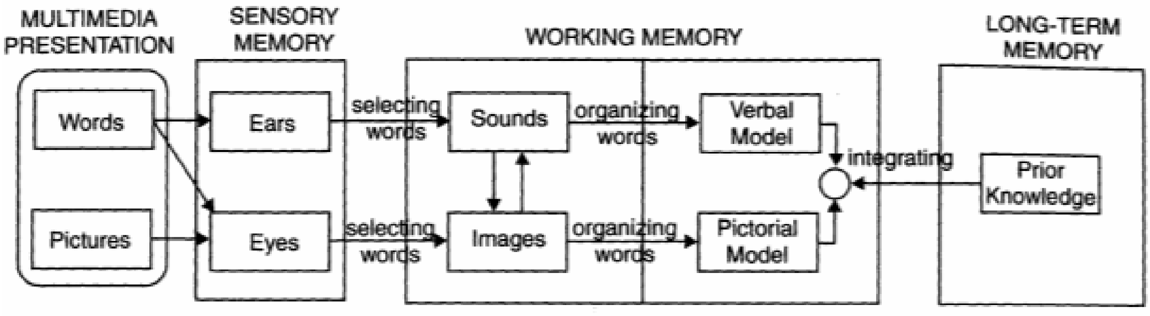


Figure 1: Cognitive Theory of Multimedia Learning (Mayer, 2009a)

Cognitive theory of multimedia learning is grounded on research in cognitive psychology which explains that the human mind when learning works within a limited capacity, processes information via dual channels, and is engaged in an active process of knowledge integration between previous knowledge and new knowledge (Mayer, 2009a). Research has shown that through learning concepts of multimedia learning, which include dual channel, limited capacity, and active learning, students improve in academic achievement, knowledge transfer, and engagement (Adams et al., 2014; Mayer, 2009a, 2009b; Moreno & Mayer, 1999). With this theory of multimedia learning expanding on cognitive load theory, providing methods to decrease cognitive load for learners, worked-example videos are a promising approach to provide equitable support for all learners, more specifically ELLs, who have shown to experience considerably higher cognitive load in the mathematics classroom (Britton et al., 1982; Campbell et al., 2007).

This research will expand on cognitive theory of multimedia learning specifically for underachieving and under-represented populations, considering the additional cognitive-load ELLs experience when learning content in a language other than their home language.

Understanding the additional processes ELLs experience, is foundational for teaching, learning, and content proficiency. In the next section, I will outline the history of Spanish-Speaking ELLs through public education, and how focus on that specific population of students has impacted public education pedagogy; specifically, how teacher and researcher practices are established, maintained, and changed to better serve Spanish-Speaking ELLs. This research will be informed by the cognitive processes ELLs employ when learning mathematical concepts, considering that mathematics often also acts as another foreign language for these students (Garrison & Kerper Mora, 1999). Through this research, I will explore the different experiences ELLs have when engaging with mathematics educational videos to inform future work on the development WEV's as well as expanding on current multimedia-learning theories. The current multimedia-learning theory by Mayer does not consider the additional cognitive-processes experienced by ELLs. This research will expand on Mayer's theory to produce a more comprehensive approach when designing WEVs and other multimedia for learning and instruction.

The Spanish-Speaking English Language Learner (ELL)

Although English Language Learners have been part of the general student population since the inception of public education here in the United States (Cardenas, 1975; Crawford, 1989; Cummins, 1979, 1983; Ruiz, 1984), strategies to address their diverse needs were not always part of the public school education process. As defined by educational researchers, an English Language Learner is a student whose first language is not English, including those students who are just beginning to learn English as well as those who have developed some proficiency (Cummins, 1983; Cummins & Cameron, 1994; Krashen et al., 1989; Lacelle-Peterson & Rivera, 1994). Unfortunately, throughout education, support for

ELLs have come only at the hands of legislation, and not an act of equity towards all students initiated by educators. As explained by LaCelle-Peterson & Rivera (1994),

> we as U.S. educators have not applied the best educational thinking to issues facing ELLs. While there have been important breakthroughs and advances in improving the quality of education for ELLs over the past three decades, most, if not all, of these advances have come through litigation and legislation – not through the disinterested pursuit of educational excellence. (p. 57)

As Spanish-Speaking ELL populations continue to increase, educators are faced with the challenge to meet the diverse needs of not only monolingual students, but also ELLs simultaneously in the same classroom. Receiving support from researchers in education, teachers began to incorporate different evidence-based strategies in the classroom. Over time, as strategies and frameworks developed out of research focused around meeting the diverse needs of ELLs, pre-packaged curriculums became prominent in schools seeking to provide diverse education options. Equitable access to education was becoming a commodity available to the highest bidder or schools with deep pockets (LaCelle-Peterson & Rivera, 1994). As researchers continued to investigate best practices for teachers, evidence-based practices for teachers circulated and found their way into the classrooms of the United States. Legislation, however, was not interested in research findings. Proposition 227 in California, passed in 1998 (Wright, 2005), set a precedent that would follow into Arizona as Proposition 207, about how to best educate ELLs, a precedent that was founded on racism, myths, profits, and not research. As stated by Jimenez-silva, Bernstein, & Baca (2016), the passage of these propositions was the beginning of initiatives seeking to eliminate bilingual education. These legislations in California and Arizona led to practices in the classroom which were more often shaped by assumptions and false notions about what is best for the ELL student, instead of evidence-based research.

Dismantling the Myths Surrounding ELLs

As populations of ELLs continued to grow in classrooms across the U.S., some teachers sought to incorporate impactful strategies to meet their diverse needs. Frameworks and teaching practices, born out of research focused heavily on language theory as well as cognition theories, began to challenge common assumptions about the best way to educate ELLs. Although teacher pedagogy specifically for ELLs has been discussed by researchers and teachers since the late 1900's (Cuevas, 1984), beliefs surrounding the education of ELLs continue to be plagued by false assumptions. The assumptions, based largely on three different viewpoints stemmed in language theory, impact how educational language policies are developed and implemented. Strongly supported by scholar Richard Ruíz (Ruiz, 1984), the three assumptions are *language as a problem*, *language as a resource*, and lastly *language as a right*.

Beginning with *language as a problem*, it is imperative to understand the implications of this ideology not only the overall culture of society, but more explicitly in education and the mentality of those in charge of creating welcoming spaces for all students, including ELLs. Operationalizing this viewpoint leads to the idea that a language other than English is a threat to the very fabric of the U.S. and often leads to incorrect assumptions. The first of these assumptions as explained by Jim Cummins (1983),

> the assumption that minority students who are academically at risk should be exposed to as much English as possible … This belief underlies the increased demand for 'English Immersion' programs in recent years and is often associated with the position that bilingualism and/or bilingual education will confuse children's thinking, and consequently, impede their academic growth. (p. 373)

This false assumption was instrumental in the push for "English Immersion" classes in the southwest United States. The English Immersion idea implemented in the U.S. was based in part off the programs implemented in Canada. These French language immersion programs in Canada were developed to promote bilingualism where students were immersed in French language classes (K. Clark, 2009). However, the actual implementation of English Immersion in the U.S. instead forced minority students into "English-only" classrooms with little to no language supports. This change in the approach to educate ELLs, instead of promoting bilingualism, forced minority students to adopt English with little to no regard to their home language. Research has shown Structured English Immersion (SEI) programs in the United States are not nearly as effective as Bilingual programs (Garcia & Figueiredo, 2012; Jimenez-silva et al., 2016; Llamas-Flores, 2013). SEI programs in the United States when implemented lacked the foundational components that made other immersion programs across the world successful.

Several studies and analyses have shown that when comparing Transitional Bilingual Education (TBE), similar to the immersion language programs in Canada, to SEI programs, TBE programs were found to be more beneficial for ELLs and that students receiving support and instruction in their native language lead to more rapid acquisition of English language proficiency (Gándara & Orfield, 2012; Lillie et al., 2012; Martinez-Wenzl et al., 2012). While extensive research showed the benefits of the bilingual programs, "English-only" legislation still moved forward to encroach on ELLs in the United States.

The two propositions for "English-only" education, Proposition 227 in California, and Proposition 207 in Arizona, opened the door to the implementation of SEI programs in both states. Best case scenario, these programs limited bilingual education and other ESL programs in each state. Worst case scenario, they completely eliminated any type of language program in schools. These propositions and implementation of SEI promoted the idea that ELL students can acquire full fluency in English in under a year if they are "heavily exposed" to it (Lillie et al., 2012; Wright, 2005). Extensive research has shown that the necessary academic English language proficiency is achieved in 3-5 years (Cummins, 1979), not in a year as argued in SEI state policies (Jimenez-silva et al., 2016). This legislation stemming from language as a problem ideology created a hostile atmosphere for teachers, parents, and ELLs, who suffered academically at the hands of failing state funded educational programs based on racist ideologies and false assumptions.

Alternatively, *language as a resource* and *language as a right* both provide for an entirely different approach to educating ELLs. This alternative viewpoint also dismantles the pedagogical assumption analyzed by Cummins (1983); "the pedagogical assumption that academic input to students (minority or otherwise) should be 'simplified' as much as possible" (p. 373). Treating students' native language as a pathway to boost academic achievement, while at the same time regarding their language skills as assets instead of deficiencies, has been proven to increase academic achievement as well as improve English language proficiency (Ruiz, 1984). Many researchers find that when doing mathematics, students that incorporate their native language as they work, experience increased engagement as well as more access to advanced mathematical material (Anchan & Soylu, 2023; Gutstein et al., 1997; J. Lee et al., 2011). While English-only education seeks to erase the home language, research has shown that ELLs home language is a rich resource students engage with and pull from daily in and out of the classroom. Through the lens language as a resource and language as a right, the assumption that English-only instruction will increase English language proficiency, is found to be obsolete and harmful. Secondly, it allows for truly effective evidence-based teacher strategies, in full support of bilingualism, strategies with built-in frameworks and practices that address the diverse issues ELLs face in schools today.

ELLs and Mathematics

As current curriculum goes through changes with reforms, “new” national standards are introduced, Common Core State Standards (CCSS), with emphasis on communicating solutions and discussing processes. These new standards, while advocating for a more critical thinking approach to education, present a new challenge for ELLs. With this recent change in emphasis, ELL students now must engage in explaining solutions, negotiating meaning of mathematical concepts, sharing arguments with others, while at the same time learning English and content (Gleason et al., 2017; Moschkovich, 2013). Along with new national standards mandated by the federal government, according to the Standards for Mathematical Practice, teachers are also expected to develop students that are mathematically proficient, students that can reason abstractly, can develop mathematical representations, can create mathematical connections, can gain procedural fluency, and communicate using the language of mathematics (E Silva, 2014; Kurz et al., 2017; Selling, 2016). With federally mandated expectations, ELLs would now face a growing number of challenges in the mathematics classroom, many of which students, teachers, and schools are ill equipped for.

As new standards were implemented across the nation, extensive research looked to provide insight into the difficulties faced by ELLs in the new mathematics classroom (Johnson & Wells, 2017; J. Lee et al., 2011), which led to the development of evidence-based strategies and frameworks to provide the necessary supports. Many of these strategies were grounded upon the finding that learning and concept proficiency happens when instruction is centered around the students’ cultural, linguistic, and personal lived experiences (Anchan & Soylu, 2023; Moschkovich, 2013; Ruiz, 1984). These findings echoed the viewpoint of language as a resource, a position which acknowledges and uses the deep resources found in both the native language and culture of the ELL. Based on extensive research, papers, and discussions from language conferences, the Stanford Key Principles for ELL Instruction by O. Lee, Quinn, & Valdes (2013) provide a detailed set of guidelines for practical application in the classroom. The second principle, "Instruction leverages ELLs' home language(s), cultural assets, and prior knowledge. ELLs'" (p. 1), argues for the ELLs home language being instrumental and should be considered an asset from which to pull from, as well as culture and prior knowledge. Riding ourselves of the deficiency perspective, instruction should look to incorporate the assets ELLs bring with them into the classroom. Research finds that English language proficiency is expedited as students are given opportunities to learn content through native language use and connections made to previous knowledge and cultural connections (Anchan & Soylu, 2023; Johnson & Wells, 2017). In the following sections, I detail how research and instruction evolved to incorporate language, culture, and prior knowledge as a resource, and not a deficiency.

Language. Although mathematics is widely considered the "universal language" due to its extensive use of symbols, it is far from being culture free. As Garrison and Mora (1999) state, "This misconception ignores the vital role of language in the development of mathematical concepts. Mathematics power is rooted in a strong conceptual understanding of mathematics, and this conceptual base is best developed through concrete experiences and language" (p. 35). Research has shown that to achieve mathematical competency, mathematical competency and language proficiency go hand in hand. De Avila & Duncan (1982) explained that ELLs often have low achievement in mathematics due to inadequate levels of English proficiency. Other researchers have argued that to make mathematics instruction accessible to all students with varying levels of English proficiency, the instruction must be made accessible through comprehensible input (Abedi et al., 2006; Garrison & Kerper Mora, 1999; Krashen et al., 1989; Office et al., 2012). As extensive research shows, the language component of mathematics instruction plays a major role in the ability of ELLs to achieve concept proficiency. As cognitive load theory and research suggests, “by introducing linguistic information that must be processed in working memory and that is extraneous to the mathematical problem”, most classroom instruction and problem-solving processes do in fact, “increase cognitive demands for students, and especially ELL students” (Campbell et al., 2007). Instruction must therefore significantly consider language and employ language acquisition theories to succeed in providing ELLs with the opportunities to achieve concept proficiency.

Language acquisition, according to Cummins (1979), “develops adequately in a transitional bilingual program … in a submersion program they are likely to perform below their potential for a variety of reasons” (p. 246). Cummins continues to explain that ELLs basic cognitive skills are less deficient when they struggle with English content, instead, he argues that increased focus on first language proficiency simultaneously leads to English proficiency as well as specific content competence. With language being such a critical challenge for ELLs in mathematics, developing strategies to increase comprehension was urgent. “According to research in psycholinguistic development and learning, one of the key elements in teaching second-language learners is what Krashen (1981) terms comprehensible input. This is a construct developed to describe language that is understandable and meaningful under optimal conditions” (Garrison & Kerper Mora, 1999, p. 35). As explained by Krashen (1981), for input and instruction to fall in the range of comprehensible, it must be slightly more complex than the English proficiency level of the student.

Through this approach, the instruction will promote second-language proficiency while simultaneously enabling ELLs to understand the mathematical content. The National Council of Teachers of Mathematics (NCTM) also advocates for this incremental approach. Standards published in 1989 by the NTCM, presented teachers with direction on how to enact this methodology in the classroom. As explained by Garrison & Mora (1999);

> These standards offer guidance on how to construct a conceptual understanding of mathematics by urging teachers to begin each new concept with concrete examples and experiences. The curriculum should then provide opportunities for students to make connections among concrete experiences, semi concrete graphical depiction, abstract symbolic representations, verbal language, and written expression to develop a thorough understanding of the new concept. (p. 36)

Although the standards provided some guidance, teachers still faced the challenge of how to make the linguistically complex language used in mathematics instruction accessible to all learners, especially ELLs. As ELLs are facing new mathematical concepts, they face many challenges. Two of these challenges are the learning of an unknown mathematical concept, and the complex unknown language used to explain the concept. Because of this dual challenge, teachers must be aware and careful to design lessons in which they consider the linguistic complexity of the language used in instruction, as well the complexity of the new concepts. Borrowing from theoretical foundations found in English-learning models, researchers sought to address these two challenges.

As explained by Cummins (1979), students transfer learning from one language to another only when a certain level of proficiency is reached in the second language. Once this threshold is reached, students are then able to successfully establish concepts and cognitive skills. As research continued to expand on language theories, teacher strategies revolved around preview-review technique, a commonly used strategy in bilingual education, described by Legarreta-Marcaida (1981) as a strategy in which the native-language of the student is used to explain new concepts and initiate learning, subsequently the second language is used to reinforce the concepts, paying special attention to new vocabulary and abstract concepts. This strategy is by design in direct opposition with legislation passed in California and Arizona, Proposition 227 and Proposition 203 respectively. Legislation that views language as a deficit, mandating English-only instruction and SEI models that followed. However, evidence-based strategies from bilingual education reinforce the approach of language as a resource. In summarizing Gándara and Contreras (2009), Moschkovich (2013) articulates the following: "research suggests that high-quality instruction for ELs that supports student achievement has two general characteristics: a view of language as a resource, rather than a deficiency; and an emphasis on academic achievement, not only on learning English" (p. 18). Through this type of intentional instruction based in evidence from research, teachers can deliver instruction as comprehensible input to students, facilitate transfer of learning from one language to another, as well as increase English-language proficiency.

Culture. The importance of student culture in the learning process is supported heavily by Sociocultural Theory (SCT). SCT's foundations explain that learning, knowledge acquisition, and meaning-making, happen through social interactions within a community (Barza, 2014; Lantolf & Thorne, 2006; Moschkovich, 2002). Culture, as defined by Gutstein et al. (1997), "The ways in which a group of people make meaning of their experiences through language, beliefs, social practices, and the use and creation of material objects" (p. 712). With these definitions in mind, we come to understand how members of a population, in this case Spanish-speaking ELLs, can develop a sense of shared identity through language, social practices, and similar home-life experiences. These definitions also tell us how the social practices come into play for ELLs, inside and outside the classroom. With renewed emphasis by new standards on students' ability to not only reason, but also orally articulate solution processes, the social practices in the classroom must provide students with opportunities to engage with mathematical social practices and knowledge, while also extending these practices outside the classroom. Gutstein et al. (1997) goes on to explain,

> we understand things as they 'fit into' that which we already know. Among the pedagogical implications is that teachers need to provide opportunities for students to develop links to new ideas, but these ideas must be within the student's potential understanding (i.e., students must be able to make the connections to their existing knowledge). (p. 711)

Students look to make connections to what they already know and make new knowledge "fit into" their already established previous knowledge. Therefore, if teachers are to provide a space where cognitive processes of meaning-making and knowledge connections can occur, they have a responsibility to develop a deep understanding of their students and provide instruction that is culturally relevant.

Championed by Gloria Ladson-Billings (1995), this approach to pedagogy is founded on a commitment to students and their communities, equity based social relations in the classroom, and a shared responsibility constructing knowledge built around the experience of students' culture. With language being so central in culture, this approach to pedagogy engages language theories by default. Studies by Mohatt & Erickson (1981) further show that instruction which utilizes language similar to the language students used at home and outside the classroom, improved student achievement beyond expectations. Similar studies by Cazden & Leggett (1976), Erickson & Mohatt (1977), Jordan (1985), Vogt, Jordan, & Tharp

(1987) showed very similar results in which the language used in the classroom for instruction was instrumental in creating a learning space in which students achieved academic success.

Recent studies conducted in modern schools & communities by Barza (2014), Correa-Chávez, Mangione, & Mejía-Arauz (2016), Hilaski (2018), and Schachner (2017) resulted in similar findings advocating for the importance of language interactions, and how language is central in student achievement. Ladson-Billings (1994) argues that student achievement depends on the "speech and language interaction patterns of the teacher and the students … student 'success' is represented in achievement within the current social structures extant in schools" (p. 467). Looking into the speech and language interaction patterns, researchers find that language acquisition theories are foundational in developing the interactions students find advantageous in learning content and learning the English language.

As students develop proficiency in mathematics concepts and English language, it is important to recognize that, while language is central in learning, at the core of mathematics instruction is developing the ability to grapple with complex mathematical concepts. Instruction that is culturally relevant to students will provide practices in which students will draw on cultural practices and begin to make new connections between rich cultural prior knowledge and new content knowledge.

Prior Knowledge. The process of building connections between prior knowledge and new knowledge, as well as connections between similar cognates in English and Spanish, is a difficult process for ELLs. Considering the cognitive demands of learning a new language, making knowledge connections becomes less important. Williams (2001) lays out a very informative description of composition of academic language encountered by students in the classroom. Due to the combination of multiple sources that make up the English language, Spanish-speaking ELLs find it difficult to make language connections. At the same time, she argues, “Because most of the language that students encounter in books is from the multisyllabic Greco-Latin origin, the reason academic language ability takes longer to develop”, 5 to 10 years, “becomes more understandable. Furthermore, Spanish-speaking students may more easily understand the connections between English and Latin because Spanish is rooted in Latin” (p. 751). Providing ELLs with a proven cognitive process in which they can detect connections between English and Spanish vocabulary, provides them with an essential tool of self-sufficiency and learning. As students become proficient in this process, cognitive demands decrease for processing language and are now available for other cognitive processes, such as building connections between prior knowledge and new knowledge. Any type of instruction which prohibits the students to engage in content through their culture and home language inherently prevents the student from engaging with their own prior knowledge. This rejection of students’ assets becomes a burden as they struggle with unknown language, which has no connection to any prior knowledge. Researcher M. Takeuchi (2016), investigating group work in the mathematics classroom, finds that through group work and student conversations, students are able to draw upon prior knowledge, from within themselves and each other, in order to form ideas and make connections. Like the Stanford principles, researchers Walqui & Heritage (2012), while also providing evidence-based principles for ELL instruction, state the following when discussing the importance of prior knowledge:

> All ELLs regardless of their socioeconomic or cultural background take to school immense resources and a range of learning skills that need to be appreciated and

> built upon. The cultural as well as social foundations of learning are important in that the prior knowledge on which students build new learning is culturally shaped. (p. 1)

Since all learning is based on prior knowledge, effective ELL instruction must account for prior knowledge and anything else is a violent rejection of a student's identity. As research and evidence-based practices informed pedagogy for mathematics teachers, there arose a need for research to also expand cognitive theory into the learning processes of ELLs specifically in mathematics. While research successfully advanced to provide strategies for ELLs in the classroom, researchers also worked to expand on cognitive theories and understand the cognitive processes employed by ELLs when learning mathematics concepts.

Cognitive Theory and English Language Learners Learning Mathematics

Expanding on cognitive theory, researchers argue that the development of home language literacy skills amongst ELLs increases English literacy acquisition, which makes possible the transfer of cognitive and academic skills from one language to another (Campbell et al., 2007; Cummins, 1979, 1983). This cognitive process of knowledge transfer then frees cognitive processes for content proficiency. When looking at current mathematics materials in the classroom, Campbell et al. (2007) finds that "materials are often written using implicit assumptions about the typical student who would use such materials at a particular developmental level or grade. For ESL students, these assumptions may be incorrect" (p. 6). As ELL students engage with these materials, they experience an increase in cognitive load, termed as "extraneous cognitive load" by researchers Paas, van Merriënboer, & Adam (1994), Mayer (2009a), and Sweller (1994), amongst others. To create spaces for effective mathematics instruction, researchers and teachers investigated ways to decrease cognitive load not only in mathematics instruction but also in the word problems used in classrooms for students to learn from as well as solve. Researchers find that to develop the cognitive processing skills necessary in ELLs as they learn mathematics, a process referred to as scaffolding, developed in the 1950's by cognitive psychologist Jerome Bruner, must be enacted by teachers and staff. Through scaffolding, instruction is intentional in developing cognitive skills via "well-designed work examples and instructional guidance" (Campbell et al., 2007). This type of instruction enables students to take ownership of their learning as they practice and develop progressively more complex mathematical processes, which are modeled by the instructor (Johnson & Wells, 2017). Researcher Donato (1994), while advocating for scaffolding strictly for ELLs, also found that the instructional strategy was beneficial for monolingual learners. This research finding was also supported by practical evidence from teachers via students' increased mathematical performance, and as teachers began to implement the strategy in their classrooms and as standardized tests showed significant improvement for all learners (Abedi et al., 2006; Wearne, D., Hiebert, 1988). Other research would continue to find that strategies developed to support ELLs would also be beneficial in supporting the general student population not designated as ELLs.

Scaffolding

Guided instruction in the form of scaffolding, in which "strategic control of learning is gradually transferred from experts to novices" (Campbell et al., 2007), allows students to see models of successful problem solving in mathematics and acquire the cognitive processes themselves. Researchers Abedi, Courtney, Leon, Kao, & Azzam (2006), in summarizing work done by Joan Williams (2001), state,

> Since academic language takes even longer to learn than survival English, Williams made specific suggestions on how teachers in of all subjects can help their ELL students: draw connections between similar cognates in English and Spanish for Spanish-speaking students; use scaffolding with visual imagery; emphasize written

> skills as much as oral skills; read aloud every day; avoid idioms; speak clearly; promote diversity; and avoid making assumptions about student understanding. (p. 8)

Connections between cognates in English and Spanish draws from both theories of language and theories of cognition. Emphasizing written and oral skills, reading aloud, all draw from theories of language, while scaffolding with visual imagery relies heavily on theories of cognitive processes. Experts in the room, teacher, or student, provide attainable processes students can strive for. Students enter these learnings spaces, understandably lacking in different way, some more than others, however through carefully implemented scaffolding, learners can develop the cognitive processes and language skills needed to engage and take ownership of their learning.

When discussing subject matter discussions in the classroom, Gándara & Orfield (2012) state "Carefully designed pedagogical scaffolding enables students to develop the skills, language and knowledge they did not have as they entered these interactions." (p. 18). Although, the process of providing adaptations to better serve ELLs is strongly supported by research (Johnson & Wells, 2017; Moschkovich, 1999a, 2007, 2013), the process itself is challenging in practice. Kurz et al. (Kurz et al., 2017) find that

> some of the preservice teachers seemed to guide the students too much (by producing pictures that really limited thinking and restricted multiple approaches or entry points) compromising students' thought processes. There seemed to be a focus on making sure the ELLs were able to get the right answer rather than providing opportunities to challenge the students at an appropriate mathematical level. (p. 45)

They go on to argue that specific consideration must be taken by the person making the modifications and providing the scaffolding, that the ELLs level of English proficiency be understood as to inform the scaffolding process. Since cognitive processing skills do not develop organically through traditional scaffolded instruction, it is imperative that instruction become intentional in providing social opportunities for ELLs to develop cognitive processes, provide effective worked examples, and develop the necessary social practices (Kurz et al., 2017; Lantolf & Thorne, 2006; Moschkovich, 1999a; Tarmizi & Sweller, 1988). In the classroom, sociocultural theory can be used to guide the ways in which ELLs make meaning and develop their own practices of knowledge acquisition, cognitive processes for learning, including reading, speaking, writing, and listening.

As stated before, mathematics instruction relies heavily on the use of language in instruction, specifically mathematical language. Kintsch & Greeno (1985), in developing a processing model for understanding and solving word arithmetic problems, bring together theories of problem solving processes with theories of processes of language comprehension, both which are essential in mathematics. They state,

> If our characterization of word-problem comprehension is correct, then it must result from a specialized comprehension process. The process is specialized at a deep level, involving the syntax and semantics of word classes, as well as at the level of higher order interpretive schemata. We conjecture that acquisition of this specialized comprehension knowledge is an important, although not universal, achievement for school children in their experience with word problems. (p. 126)

This finding stresses the importance of students acquiring specialized comprehension knowledge for problem solving. For ELLs, this presents an extra challenge as they grapple with an unknown language, on top of difficult mathematics specific syntax, words, and practices.

Social Practices

Stanford's Key Principles for ELL Instruction (O. Lee et al., 2013) provide a robust outline of for instruction for ELLs. The first principle, "Instruction focuses on providing ELLs with opportunities to engage in discipline-specific practices which are designed to build conceptual understanding and language competence in tandem." (p. 1), helps to unpack the classroom as a social space in which social practices are on display and are developed by the teachers and students. The difficulty of language use and acquiring mathematical discourse practices are addressed by active strategies that provide ELLs with opportunities to engage in mathematical discourse in the classroom as they develop English language proficiency simultaneously with mathematical concept proficiency. By using frameworks provided by Sociocultural Theory (SCT), instruction can provide opportunities for ELLs to engage in social practices designed to develop their cognitive processes as well as specific discourses used in the mathematics classroom. Championed by Russian psychologist L. S. Vygotsky, SCT posits that cognitive processes and knowledge are essentially constructed via social interactions guided by language, culture, and the physical space (Lantolf & Thorne, 2006). Through a sociocultural lens, instruction considers the lived experiences of ELLs in and outside the classroom, and actively ensures that the functions of language and culture are positively appropriated towards a learning environment. In a study focusing on mathematics instruction, Abramovich & Connell (2014) states, "From a sociocultural perspective, learning of mathematics results from active participation in a culturally accepted mathematics practice and is co-constructed by active interactions between the learner and his or her culture" (p. 3). In establishing the classroom as a community of mathematical practice, teachers create a space in which students see mathematics practices modeled, get a chance to practice these norms, as well as develop content proficiency.

Instruction that deliberately creates a community of practice for students, enables them to identify as learners and participants of practice and knowledge creation. Walqui & Hertiage (2012) explain, “Communities of practice are organized so that learning occurs in ways that contribute to the students’ development of strong identities as learners and as effective participants in the social practices of their learning community” (p. 3). As ELLs contribute their own prior knowledge, culture, and language to the community of practice in the classroom, they identify as learners and investors in the learning process. Research has shown that students who are actively participating in the learning process, retain knowledge and develop cognitive processes more than traditional lecture based instructional models devoid of active student participation in communities of learning (Barza, 2014; Hilaski, 2018; Moschkovich, 2002; Walqui & Heritage, 2012). Newly introduced Common Core State Standards (CCSS) for students include the use technology, “Mathematically proficient students consider the available tools when solving a mathematical problem. These tools might include pencil and paper, concrete models, a ruler, a protractor, a calculator, a spreadsheet, a computer algebra system, a statistical package, or dynamic geometry software” (E Silva, 2014, p. 1), within these social practices, researchers and teachers must also realize how advancements and integration of technology changes pedagogy, classroom culture, and the learning process.

Technology

When considering technology, researcher M. Goos (2005) states, “From a sociocultural perspective, technologies such as computers and graphics calculators can be viewed as cultural tools that not only reorganize cognitive processes but also transform classroom social practices” (p. 39). As modern-day students enter the classroom with ample prior experience using technology in the form of handheld mobile devices and personal computers, researchers look to understand how these experiences help shape the learning process as well as how experiences with technology informs the ways students create meaning and practices of learning in the classroom. In support for the use of technology in the classroom, J.E. Silva (2014) states,

> school has never been as efficient as the society desires and so new approaches are normally welcome (at least by most people); secondly, if the school is to prepare students for 'real life' and for some professional activity, then teaching should somehow incorporate the technological tools that students will find someday in their adult life. (p. 3).

While there has been research refuting the use of technology on the grounds of the means of instruction has no effect on learning (see R. E. Clark, 1983, 1991), proponents of technology in the classroom, Schmid et al. (2014), argue that, "in most if not all learning situations there is shared cognition among the learner, the task itself and the tools that the learner uses in the process" (p. 272). Looking to expand on cognitive theory, research suggests that technology integration in the classroom can have significant impacts in student learning practices, classroom social norms, as well as the process of instruction. Findings suggest that technology plays an important role in the entire process of learning by also activating essential cognitive processes.

Studies investigating the impact of the technology in the mathematics secondary classroom discovered that while technology can be a tool for effective teaching, time must be intentionally invested in ensuring technology does not become a gimmick of little-to-no actual benefit in the classroom (Braun et al., 2014; Chen et al., 2016; Lape et al., 2014; Toivola & Silfverberg, 2014). Researchers Schmid et al. (2014), in a meta-analysis of technology in education state, "Like any tool, its effectiveness is determined by the purpose it serves and the manner in which it is implemented" (p. 271). Like computers, calculators, and other technologies, the incorporation of instructional videos in the classroom considerably changed the educational landscape. While instructional videos have always been present in education to some degree, mathematical educational videos gained great popularity as the "flipped classroom" began to propagate itself in classrooms across the nation. The idea born out of frustrated teachers Jonathan Bergmann and Aaron Sams, "struggling to find the time to reteach lessons for absent students, they plunked down $50, bought software that allowed them to record and annotate lessons, and posted them online" (Tucker, 2014). They found that it wasn't only the absent students that engaged with educational videos, but students who had attended the class, also watched, and benefited from the recorded lecture videos. With the flipped classroom models, teachers took to task to creating and recording engaging lectures for students to watch at home, while classroom time was spent practicing problems, exploring higher level concepts, and answering students questions (Bishop & Verleger, 2013; Chen et al., 2016; Tucker, 2014). As demand grew for flipped classroom content, the library of online instructional videos grew exponentially as teachers, students, and non-educators created content accessible to anyone with internet access.

Instructional Videos

Instructional videos have provided educational support for many years. "Video has the ability to convey material through auditory and visual channels, creating a multisensory learning environment" (Hibbert, 2014, p. 1). The ability to provide a multisensory learning environment for the student, individual unlimited access to lecture content, and portability, makes the instructional video a very attractive tool for educators and students. Students seeking resources outside the classroom have an unlimited reach via the internet, "sources of online homework help include the vast array of instructional videos and tutorials that have been produced by enthusiasts and experts for public use, such as those found on www.youtube.com and www.khanacademy.org" (van De Sande et al., 2014, p. 460). As popularity spreads, researchers and teachers must investigate the implications instructional videos will have for the ELL in the mathematics classroom. According to M. Hibbert (2014), students find instructional videos helpful when the video is real world relatable, not riddled with highly academic language, and vividly connected to content. As ELLs grapple with instructional videos, research must view this interaction as a student learning a foreign language. Not only is English a foreign language to the ELL, but mathematics also presents itself as a foreign language. With the internet so easily accessible for most of the student population, and a myriad of available instructional videos, little research is available investigating effectiveness and how students experience instructional videos. Research by van De Sande et al. (2013) articulates, "although Khan Academy (www.khanacademy.org) has published more than 4,000 instructional videos covering K-12 school topics, we do not know (other than anecdotally) how watching these videos translates into learning or resolving student questions" (p. 35). There is, however, little research via the flipped classroom model, that may provide some insight into the experiences of ELLs, as well as implications for future research.

Graziano & Hall (2017a) in a study investigating the experiences of ELLs in flipped mathematics classroom, found that the majority of students, 30 out of 39, found the instructional videos challenging, that 22 out of 39 found the videos engaging to some degree, and lastly, that 30 out of 39 students found the videos helpful in learning algebra. The study found that the flipped classroom itself did not produce improvements academically, however, students shared they were more engaged in the class due to the videos, when compared to traditional lecture methods of instruction. Students in this study also felt that they improved in English-language proficiency. Graziano & Hall (2017) explain,

> students found the videos and in-class activities helpful in improving their English literacy skills. These findings did not surprise us since practice in speaking and writing as well as reading and listening contribute to the overall improvement of second language knowledge" (p. 189)

Research focusing on the specific and individual experiences of ELLs when engaging with instructional videos is scarce. Researcher H. Hung (2015) offers student voices, "I like that we watch videos and self-study vocabulary at home prior to class, so when we get to class, we can practice what we have learned with our classmates and actually use English for communicative purposes" (p. 91). Students expressing the importance of being able to practice learned content, while also actively using English for classroom communication, is a very important finding of this study.

In another study, B. Freeman (2010) investigates the effectiveness of a digital mathematics intervention HELP, in which students interact with "multimedia, including, audio, video, text, and interactivity synchronized to create a visual connection between words, symbols, and meaning" (p. 69). The software HELP makes use of ELLs home language of Spanish in many of the audio and video components, while also providing Spanish translation for every interaction for students that need additional support. According to the study, the use of the math intervention, HELP, which included heavy use of educational videos, led to significant increase in math ability and increase in self-efficacy for participating ELLs (Freeman, 2010).

While the incorporation of technology often ends up being beneficial, initial attempts to incorporate technology into the classroom are not only met with resistance from teachers, but also often not incorporated carefully. History has shown that education has always been reluctant to allow new technology into the classroom, and when it is introduced, the process for a seamless and productive implementation is seldom the case.

As technology continues to make significant advances, education seeks to harness the power of technology in teacher pedagogy, student engagement, and classroom instruction. As explained by Lavicza (2008), “the emergence of new technologies available for teaching opened new perspectives and intensified demands for the changes in teaching practices” (p. 1). As new technologies emerge, educators look to incorporating them in the classroom as quickly as possible, while researchers develop studies to discover which technologies would provide the most positive returns in the mathematics classroom. Thornburg (1999) when talking about the power and opportunities of technology explains, “Their power comes not just from the fact that technologies allow us to do old jobs in new ways, but that they can be used to help us do things in education that were heretofore impossible” (p. 1). With heavy focus on pedagogical implications, researchers sought to discover how technology could allow teaching pedagogy to evolve to address the many struggles teachers face. Advanced students losing interest, students needing more one-on-one support, language barriers faced by English Language Learners (ELLs), and varying learning styles, are just some of the many struggles in the mathematics classroom, which educators and researchers wanted to investigate how technology could play a role in overcoming these challenges. In this next section, I will trace the history of technology in the mathematics classroom, the principles which guide the use of technology, how accessibility has transformed teaching mathematics the classroom, and lastly the effects on teachers, students, pedagogy, and learning of mathematics.

Calculators

With the development of the mainframe computer in 1942, technological advances in computing intrigued mathematicians and mathematics educators (Bokhove & Drijvers, 2010; Kelly, 2003; Martzloff, 2007; Schmid et al., 2014). Further developments in computing led to the first four-function calculator in 1967 by Texas Instruments, code-named "Cal-Tech". As explained by Brendan Kelly (2003), "Cal-Tech, capable of performing the four basic operations on numbers up to six digits and displaying answers up to twelve digits on a thermal paper-tape print-out" (p. 1052). The Cal-Tech was followed up by the first handheld calculators, introduced to the world by Canon, Inc. in 1970, which while portable, was extremely expensive, selling for $400 (Ball, 1997). Development continued on the hand-held calculator and prices continued to drop until 1975, when with other technological advancements, four-function calculators were available for less than $20, and by 1979 with the development of LCD displays and solar power, prices dropped below $10 (Kelly, 2003). As the calculator became affordable, it began to find its way into more households and public-school classrooms.

The introduction of the calculator into the mathematics classroom came with much heated debate. Proponents of the calculator argued for efficiency in calculations and advancing towards a technological future that will prepare students for the challenges of tomorrow (E Silva, 2014; Fey, 1989; Kaput & Thompson, 2012). Researcher Dedee Pendleton (1975) writes,

> Instructors who are using them … say that calculators stretch the student's interest, allow for more relevant kinds of problems (how far is it to the moon?) and increase motivation. Because of their speed and accuracy, calculators lend themselves to complicated problems previously avoided by grade-school teachers. (p. 1)

Opponents of the calculator argued for human capability to perform calculations and the necessity of rigorous mathematics for the development of critical thinkers not bounded by technology, as well as the implications of lack of access to a large majority of the student population (Ball, 1997; Waits & Demana, 1993, 2000). Deedee Pendleton offers us the following insight into the argument of calculator opponents;

> Opponents of calculators say that kids won't know how to count if their calculator batteries ever go dead, just as TV-oriented students no longer seem to know the basics of grammar and spelling. The device, critics contend, will make pencil-and-paper math obsolete. (1975, p. 1)

Research investigating the effects of the calculator in the mathematics classroom showed that calculators can impact the learning experiences of students. In a meta-analysis, Hembree et al. (1986) found that students at almost all grade levels performed better when using calculators, and their paper-and-pencil skills did not diminish with calculator use. However, as Waits & Demana (2000) explain some of the changes in the beginning and as calculators became more complex, "as we learned from our personal teaching experiences before and after calculators were available. For example, some paper-and-pencil applications have simply become obsolete" (p. 4); some applications being paper-and-pencil long division, calculating logarithms via product rules, graphing rational functions via first and second derivatives, integrations, and finding real and complex solutions to equations, are some of the things calculators were able to do for students which were no longer necessary to do on pencil-and-paper as calculators became more advanced (Waits & Demana, 2000). With the addition of the calculator to the arsenal of tools available in the mathematics classroom, some of the traditional methods of mathematics become less important, while others rise in importance.

While students experienced significant learning differences, the calculator also impacted teacher pedagogy. As students continued to struggle in the mathematics classroom, researchers and educators continued to work to find ways to improve student academic achievement. "The observed weaknesses in students' mathematical preparedness and the availability of technology prompted numerous mathematicians to experiment with innovative teaching and a number of them have turned their attention to pedagogical issues." (Lavicza, 2008, p. 1). As calculators began to find their way into the mathematics classroom, teachers began to realize that simply having the tool in the classroom was not enough. Teachers had to now learn how to utilize them, teach students how to use them as well, and effectively employ them through instruction and student learning. As Waits & Demana (2000) point out, "The adoption and use of technology requires additional teacher in-service training that addresses conceptual and pedagogical issues" (p. 3). As educators and researchers would learn, simply knowing how to use the technology, and demonstrating the use to the students would not be enough. Educators would need to spend time learning the technology and investigating how to best implement it in the classroom. The power of technology required teachers to rethink their role in the classroom, and some even felt threatened by the introduction of this technology. Kelly (2003) states,

> Many teachers were also threatened by the four-function calculator. A large part of the elementary school mathematics curriculum was concerned with the teaching and learning of the algorithms for the four arithmetic operations, and the machines, it seemed, would undermine the teachers' raison d'être. What would they teach to fill the void? (p. 1053)

Although teachers struggled to find more uses for the calculator, other than to check paper-and-pencil answers, as use continued, they began to see the calculator as a viable tool for solving problems and an important component of learning and instruction (Ball, 1997; Dunham & Dick, 1994; Waits & Demana, 2000). This change from just a tool to check work, to component of instruction sparked extensive research into the role of technology, in this specific case calculators, in instruction. Researcher Thornburg (1999) points out, "We have the opportunity to use technologies in ways that support modern pedagogical thought devoted to the premise that all are capable of learning, even if the pathways for each learner are different" (p. 1). With time and practice, teachers were able to realize that technology would open the door for instruction that would move beyond proficiency in hand-calculations and instead focusing on the meanings of the four main mathematical operations and when these operations should be applied in the problem solving process (Pendleton, 1975). Teachers also began to see the addition of technology, when available, as a form of providing equitable academic support to all students, specifically low-achieving students struggling with mathematics concepts. Some studies found that specifically for testing, the addition of calculators produced an increase in scores in basic calculation operations as well as problem solving for low- and high-achieving students (Hembree & Dessart, 1986). With the calculator becoming a staple in the mathematics classroom, newer technology sought to enhance learning and instruction just like the calculator did. With the appearance of the personal computer in the late 1970's, the world beyond education began to see changes, and these changes would eventually make their way into the classroom.

The Personal Computer

As developments in microcomputing led to the affordable four-function calculator, continued advancements in the miniaturization of the computer chip and other computer components, the previous mainframes which needed entire rooms, were now becoming smaller and smaller. With the first personal computer, introduced by Commodore in 1977, further iterations by Apple, and then by IBM, led to the first standard machine in business and post-secondary education. During this era, Apple computers dominated schools due to cheaper units, preferred graphical interfaces with vibrant colors, and their initiatives to partner with educational institutions to develop software that could be used in the classroom (Becker, 1987; Karp & Schubring, 2014). As technological improvements continued, computers became faster, smaller, able to handle and store more information, and improved displays. As with all technology, educators, students, researchers, parents, computer suppliers, and anyone else involved had a different vision for the purpose and use of the personal computer in education. Author Robert P. Taylor (1980) sums up the various visions eloquently into three categories, computers as a tool for learning and instruction, computers as a tutor, and lastly, computers as a tutee.

With computers making their way into homes all over the world, and companies competing to win contracts to supply classrooms, the personal computer became the new technological novelty. Software companies scrambled to provide educational coursework for schools, as well as software students could use with little to no help from the instructor. With interest from the business sector, computers began to take their place as an accessible tool in the classroom. The computer in the classroom started as a tool, the most common use, and the use that requires the least investment. Taylor (1980) explains,

> the classroom computer need only have some useful capability programmed into it such as statistical analysis, super calculation, or word processing. Students can then use it to help them in a variety of subjects. For example, they might use it as a calculator in math and various science assignments, as a map-making tool in geography, as a facile, tireless performer in music, or as a text editor and copyist in English. (p. 244)

With all these multiple uses, researchers and software producers worked to develop useful programs for the mathematics learner, which often turned the personal computer from just a tool the students and educators employed, to a self-guided tutor utilized by students. Popular tools in the mathematics classroom included Computer Algebra Systems (CAS), MuMath, Mathematica, Maple, and Derive, are just some of the software packages that made their way into the classroom, of which some behaved like tutors.

Unfortunately, simply pushing new technology and software into the classroom and into the hands of educators would come with downfalls. Teachers and students would not have the knowledge to utilize the computers and programs, and therefore, some saw the new technology in the classroom as a failure. Waits & Demana (2000) explain,

> Arguably the most important thing we learned has to do with desktop computers and why they had very little direct impact on the teaching and learning of school mathematics … Whereas teachers became very excited about the possibilities, most students in most schools, we discovered, had very limited, if any, access either to desktop computers or to mathematics computer software in their mathematics classrooms. (p. 2)

While this was a huge struggle for educators, the process of developing the software for computers forced educators to re-examine concepts and curriculum development. Educators involved in the software development process had to confront the need to overhaul much of the traditional secondary education mathematics curriculum (Kelly, 2003).

While the initial introduction of the personal computer into the classroom was not as successful as expected, educators were forced to critically analyze current curriculum and eventually reforms followed across the nation. Two reports sparked initial reforms in mathematics curriculum around the time the personal computer was beginning to make its home in the classroom. The National Science Board Commission on Precollege Education in Mathematics, Science, and Technology released a report in 1982, *Today's Problems, Tomorrow's Crises*, which criticized the current state of the quality and quantity of precollege education in the United States. The report states, "We appear to be raising a generation of Americans, many of whom lack the understanding and the skills necessary to participate fully in the technological world in which they live and work" (1982). Putting pressure on the need to improve understanding of current technology, the report exhorts educators improve the preparation of all citizens in various fields of study. The second report, by National Commission of Excellence in Education, published in 1983, *A Nation at Risk: The Imperative for Educational Reform*, also sought to shed light on deficiencies in the status of education. In the introduction, they state "the educational foundations of our society are presently being eroded by a rising mediocrity that threatens our very future as a Nation and as a people" (1983, p. 112). Both of the reports cited mostly reasons for national security; regaining status as the "unchallenged preeminence in commerce, industry, science, and technological innovation" (p. 112), "development and maintenance of our Nation's economic strength, military security, commitment to the democratic ideal of an informed and participating citizenry, and leadership in mathematics, science and technology" (National Science Board Commission on Precollege Education in Mathematics, Science, 1982, p. 1). Although both reports were important in educational reform, they did very little to argue for the importance of knowledge for the individual or the community.

While the reports advocated for a revolution in curriculum and instruction, they failed to capture the broader possibilities of technology. Thornburg (1999) tells us,

> By thinking of technologies in the broader sense as extensions of mankind, we give ourselves the capacity to see both the power and the opportunity these new tools

> afford. Their power comes not just from the fact that technologies allow us to do old jobs in new ways, but that they can be used to help us do things in education that were heretofore impossible. (p. 1)

Feeling the pressure from these reports and other studies, the National Council of Teachers of Mathematics (NCTM) released a collection of articles in 1985 with many suggestions for reform in secondary school mathematics regarding the inclusion of modern technology. While technology itself did not spark the educational revolution in the 1990's, it was responsible for forcing educators and researchers to re-consider how to adequately incorporate new technologies in the mathematics classroom, which eventually led to a revolution of curriculum and instruction. In response, professional development was developed and made part of teacher preparation in universities across the nation. Researchers and educators quickly discovered that implementing new technology was futile, unless teachers were not only properly trained, but also are buying in and believing in the power of the technology. "The key idea to keep in mind is that the true power of educational technology comes not from replicating things that can be done in other ways, but when it is used to do things that couldn't be done without it" (Thornburg, 1999, p. 7). With support from research, teacher preparation programs, as well as professional development within school districts, there was a mobilization to include training with technology. Teachers were able to receive training necessary to employ the myriad of software programs available through the personal computer, and students eventually benefited from their use of the computer as a tool, tutor, and tutee, as they also gained experience with the personal computer. As quickly as the personal computer came into the classroom and sparked a revolution in curriculum and instruction, the next technological advancement for mathematicians surfaced in the form of the graphing calculator.

Graphing Calculator

The graphing calculator is the product of the evolution of the four-function calculator through the 1980s and 1990s and the incorporation of personal computing concepts. In 1985, Casio released the world's first graphing calculator, the Casio-FX7000. The introduction of this calculator completely reshaped the text-only display into a rich text-and-graphics display (Ball, 1997; Waits & Demana, 1993, 2000). Other companies began to build upon the new technology, Hewlett Packard, Sharp, and Texas Instruments, who currently dominates the graphing calculator market. Texas Instruments made the next significant advancement in graphing calculator technology when it released the TI-81 in 1990 for $110, which according to Kelly (2003), "became the first widely used graphing calculator in secondary schools" (p. 1072). Later iterations of the TI-XX that would move the field forward were the TI-85, which allowed for transfer of data to another TI calculator. Followed eventually by the TI-92, which allowed for communication not only with other calculators but also with computers. With technology continuing to move forward, these graphing calculators continued to provide added functionality that was not so easily available to students before. The ability for running programs on the graphing calculator opened possibilities for students and educators to build their own tools necessary in the mathematics classroom, which transformed the technology into the tutee. As the tutee, the student or educator now needed to teach the computer through programming, how to perform mathematics. This role for the computer and calculator was significantly powerful. Researcher Taylor (1980) explains the benefits,

> The benefits are several. First, because you can't teach what you don't understand, the human tutor will learn what he or she is trying to teach the computer. Second, by trying to realize broad teaching goals through software constructed from the narrow

> capabilities of computer logic, the human tutor of the computer will learn something both about how computers work and how his or her own thinking works. Third, because no expensive predesigned tutor software is necessary, no time is lost searching for such software and no money spent acquiring it. (p. 245)

This process of tutoring the computer allowed the students to gain deeper understanding as they explored how to manipulate and understand mathematical processes. Teachers were able to broaden their understanding of the education process as they mentored students through the tutoring process, as well as gain understanding and master the tool being employed in the classroom. Thornburg (1999) explains the importance of the teacher fully understanding the scope and use of the new technology, "Any educator should be able to explain the curricular and pedagogical objectives of any tool in the classroom, whether it is a book, the blackboard, or a computer connected to the internet" (p. 6). As the advancement of the graphing calculator continued, so did teacher understanding of the implications on pedagogy and learning processes. The incorporation of the graphing calculator, like other previous technologies, forced educators to again examine curriculum and instruction, reforming it to efficiently incorporate graphing calculators.

Early research into the use of graphing calculators, Waits & Demana, F. (1993) show that students and teachers often worked together to create programs that allowed for formulas to be computed by the calculator by simply prompting for needed values for the formula, examples like the Quadratic Formula, Statistical Measures, and Financial Formulas are just some of the tools programmed by students and teachers. Graphing calculators also allowed students and teachers to explore specific content in real time without the need to rely on time consuming paper-and-pencil options. With the integration of calculators, basic skills began to evolve beyond just manual computations. As explained in a report *Everyone Counts* by Mathematical Sciences Education Board (1989),

> Basics from the past, especially manual arithmetic, are of less value today than yesterday - except to score well on tests of basic skills. Today's students need to learn when to use mathematics as much as they need to learn how to use it. Basic skills for the twenty-first century include more than just manual mathematics. (p. 63)

Mathematics education was continuing to evolve to address the way computers were being used in the teaching and learning process. Basic mathematical skills were no longer simply mental computations or calculations by hand on paper-and-pencil; basic skills now included efficient use of the calculator for computations and problem solving.

This important evolution in basic skills forced educators to begin to re-think their teaching practice. Calculators and computers allowed educators to focus on deeper concept understanding, as the traditional drill-based learning was no longer necessary. Basic skills no longer needed to focus on arithmetic, as much as on how to become proficient in utilizing technology. As asserted the Mathematical Sciences Education Board (1989),

> The ready availability of versatile calculators and computers establishes new ground rules for mathematics education. Template exercises and mimicry mathematics—the staple diet of today's texts—will diminish under the assault of machines that specialize in mimicry. Instructors will be forced to change their approach and their assignments. It will no longer do for teachers to teach as they were taught in the paper-and-pencil era. (p. 67)

The difficulty teachers faced was breaking away from teaching mathematics the way they were taught, from Elementary through Higher Education. Mathematics teachers tend to replicate their learning experience, and thus the challenge was to unlearn and relearn a new pedagogy involving technology. Efforts would then need to be made to help teachers transition from a classroom with very little computer-like technology, into a classroom in which the computer and/or graphing calculator was instrumental in learning and instruction.

As schools and companies worked diligently to provide access to technology for teachers and students, relevant teacher professional development on technology use was an afterthought. Researcher Forgasz (2006) explains, "Keeping abreast of the technological advances also presents challenges to teacher education institutions, placing enormous demands on course contents, resources, and the appropriate re-skilling of teacher educators themselves" (p. 438). Institutions of higher learning saw the need to provide pre-service teachers with adequate training in technology integration, but also the need to re-skill the professors at these institutions, whom were not adequately prepared for the changes in education brought upon by the integration of technology. While institutions of higher learning made progress in modifying curriculum to address the lack of teacher preparation, programs like Preparing Tomorrow's Teachers to Use Technology, invested heavily "to help transform teacher preparation programs so teachers can make more effective use of technology as an instructional tool" (Russell et al., 2003, p. 298). The integration of technology was having impacts beyond just the classrooms as tech companies became invested in such programs that worked to prepare teachers for the new classroom with integrated technology. Technology integration and teacher preparation eventually made its way into federal legislation. Russell et al. (2003) state in their study of teacher technology use,

> In a 2000 report, the U. S. Department of Education stated that "teachers' preparation and training to use education technology is a key factor to consider when examining their use of computers and the Internet for instructional purposes" (p. iii). In response to this need, the No Child Left Behind Act of 2001 (Pub. Law No. 107-

> 110) requires recipients of technology grants to invest a minimum of 25% of the awarded funds in professional development related to instructional uses of technology. (p. 298)

Thus far, the integration of technology in the classroom has impacted student learning processes, curriculum and instruction, teacher pedagogy, higher education teacher preparation programs, and lastly, federal legislation. The widespread impact of integration of technology could not have been predicted by any of the first adopters of such technologies. However, it is important to keep in mind that as computer technology continues to advance, so must efforts to adequately integrate, and prepare educators to do so effectively. At the end of the 20th century, with the graphing calculator being the center piece of technology-based activities in the mathematics classroom, the next technological advancement, the internet, would open the door to unlimited potential for acquiring and sharing information.

The Internet

While the personal computer and various calculators significantly changed the mathematics classroom, the introduction of the internet would revolutionize schools entirely. As a network of computers, the internet, in its inception, connected mostly military and academic networks in the 1980s. While education was still getting adjusted to the graphing calculator, researchers and scientists were already working on the next innovation. As explained by Leiner et al. (2001), “by 1985, Internet was already well established as a technology supporting a broad community of researchers and developers, and was beginning to be used by other communities for daily computer communications.” (p. 8). In the 1990s, commercial networks and other enterprises would begin to join the network and it would also begin to be commercialized and made available to everyone. Internet service providers began to make internet service available to homes as quickly as equipment would allow. By the fall of 1997, according to a report by Bare & Meek (1998) for the National Center for Education Statistics, 78 percent of U.S. public schools had some sort of Internet access. While this figure may seem praiseworthy, it does not paint a clear picture of true access by students and educators. In the same report, they go on to analyze access in instructional rooms and find that only 27 percent of instructional rooms in 1997 had internet access, and even in those rooms, students did not always have access to the internet. As time passed, and technology became more accessible, those numbers changed. By 2005, nearly 100 percent of all public schools had internet access and 94 percent of public-school instructional classrooms had internet access (Wells & Lewis, 2006). In its inception, the internet was rather slow, only allowing for electronic mail as its main function. Over time, file sharing became common, text-based chat rooms were developed, information sharing through websites blossomed and eventually, as the technology continued to advance exponentially, speeds increased, access became easier, and the modern-day internet was born.

With the modern-day internet in place, classrooms now have access to information like never before. Traditionally, classrooms functioned in isolation, with little to no connection to the outside world. With today's technologies, the traditional classroom has been transformed to enable communication and collaboration all over globe. As Coley, Cradler, & Engel (1997) explain in their research, "The availability of Internet access allows students and teachers to communicate with other students and teachers and to expand their use of teaching and learning resources" (p. 17). While in traditional classrooms, the teacher was the sole gatekeeper of information and learning, with technology, infinite sources of information are available at the students' fingertips. Internet connections and computers make it possible for students to access very rich information and multimedia sources of learning, as well as other students and teachers in different parts of the world. In a study investigating the effects of computer use, Fiorini (2010) finds that computer and internet use is on an upward trend in many countries, some close to reaching 100% home computer ownership. The global adoption of the internet has made education more accessible in very remote areas. The shift in access has opened opportunities for non-traditional educational methods to flourish. Some of these methods include the use of computers and internet to deliver instruction, instead of the traditional method of teacher in a room filled with students. One of these methods that exploits the far and easy access of the internet, is the Flipped Classroom.

While concepts and theories used by the flipped classroom model had been circulating the educational field since the early 1990's, (R. M. Clark et al., 2016; Crouch & Mazur, 2001; King, 1993; Lage et al., 2000; Mazur, 1997; Sams, 2011). The core idea behind the flipped classroom is that instruction is no longer in the classroom but accessed at home, individually by each student through the form of an educational video. Bergmann and Sams would create these videos on their own, and students would watch them independently. Ideally, students can watch the instruction at their own pace, with the freedom to pause, rewind, and fast-forward as needed. Time in class is then spent on practice, deeper learning, clearing up misconceptions, and collaboration, amongst others (Graziano & Hall, 2017b; Toivola & Silfverberg, 2014; Tucker, 2014). As research has shown, simply providing videos, without other supports in place, would not be an effective flipped classroom. Careful consideration must be taken by the educators to ensure students are engaging with the videos and are spending their time effectively with the videos, as well as in class (Bishop & Verleger, 2013; R. M. Clark et al., 2016). With the flipped classroom gaining popularity, educators and researchers wanted to understand what made this non-traditional model so effective. Findings showed that the foundation of the flipped classroom was an engaging video, rich with knowledge and easily accessible to the diverse student populations (Braun et al., 2014; R. M. Clark et al., 2016; Hung, 2015). As technology continued to advance, and education began to evolve away from the traditional teacher in the classroom model, educational videos flooded the internet. With early influence to change the way education looks, starting with Salman Khan with Khan Academy in 2006 (Thompson, 2011), videos and other forms of multimedia have changed the way we now look at education, specifically mathematics. Explained by Thompson (2011),

> Math is the killer,' Gates told me recently. His foundation had researched unemployment and found math to be a significant stumbling block. 'If you ask people, 'Hey, there are these open nursing jobs, why don't you go and get one?' math is often the reason they give for not applying.' Gates says. 'Why don't you pass the Police exam? Math. (p. 3)

Videos and multimedia accessed on the internet quickly became the next tool to be used in the mathematics classroom.

Videos and Multimedia

While video and multimedia were not an invention for education, they've been a part of the realm of education for many decades. With the television beginning to become part of the public-school classroom in the 1950's, multimedia quickly became mainstream in the classroom. Although multimedia has changed drastically since its introduction via the television, it has remained a common tool for educators to engage students. With origins from the discipline of music, the term multimedia has been used to encompass the types of engagement to be experienced by concertgoers in the late 1960's. Through time, the term has taken on different definitions, depending on the context of use. Multimedia, as defined by Ambron & Hooper (1988) is "the innovation of mixing text, audio, and video with a computer" (p. 5), strikingly similar to a definition offered by Vaughan (1993), "Multimedia is any combination of text, graphic art, sound, animation, and video that is delivered by computer." (p. 7). Proclaimed as the latest innovation for learning and instruction, researchers and educators looked to address the traditional and ever persistent challenges students face in the classroom. According to proponents, multimedia would effectively decrease time-in-training, increase achievement, content retention, consistency, flexibility, access, motivation, and fun for students (Helms & Helms, 1993). With computers reaching nearly 100% access to all public-school students, multimedia for learning and instruction would create non-traditional educational spaces all around the world. In the book *The science of learning: Determining how multimedia learning works*, Mayer (2009b), while focusing on the cognitive theory of multimedia learning and how through various studies, multimedia was showing promise to be an effective approach for becoming another tool for learning and instruction. As computers in the form of mobile devices continued to make their way into classrooms and homes, multimedia methods of learning also became easily accessible.

With computers being used in the broad sense to include devices with electronic circuitry and some sort of electronic processing unit, the definitions of multimedia offered by Ambron & Hooper (1988) and Vaughan (1993) continues to hold validity. In the classroom, multimedia began to be delivered through televisions in the early 1950's, then through projectors and computers as they became available in the 1970's, and in today's modern classroom, multimedia continues to be delivered through personal computers as well as through the mobile devices made possible through the miniaturization of computers and electronic devices. Although multimedia has had a home in the public-school classroom since the early 1950's, recent research has articulated that the term multimedia generally is limited to the combination of media via the personal computer and mobile device (Bulman

& Fairlie, 2016; Gotsick & Gotsick, 1996; Greher, 2004; Helms & Helms, 1993; Leow & Neo, 2014). With this specification in mind, researchers sought to discover how did multimedia impact the learning and teaching process in the mathematics classroom, as well as education across the nation.

In a study investigating the innovations made in the classroom, researchers Leow & Neo (2014) found that with the growing access to the internet, information became easily accessible and so software developers looked to develop computer-based learning programs. These programs shifted the type of pedagogy from teacher-centered instruction to learner-centered instruction. In their study, they explain, "In recent years, multimedia has introduced the pedagogical strength in facilitating student learning and supplementing learning with liveliness as it adds richness and meaning to the information presentation with the use of more than one medium" (p. 100). Other studies investigating the effects of multimedia on the experience of learners find that students take ownership of the learning process and can navigate the different sources of information in a shorter time, when compared to the traditional learning model in which the teacher navigates the sources of information (Hede & Hede, 2002; Parekh, 2006). With multimedia as the method of instruction, students are now able to self-adjust their learning trajectory and timeframe for the processing of information individually. Traditionally, students are subjected to a "one-size-fits-all" approach instruction, in which the educator moves through content at a pace which is believed to allow students to achieve concept proficiency. As students take control of their individual learning experience through non-traditional methods, they are then engaged with the content on a deeper level and inherently become active participants in the instruction process. This shift of teacher and learner roles allowed teachers more freedom to engage students needing more support, as they struggled with challenging concepts.

With this shift in instruction, many educators feared that multimedia would finally bring an end to the need for educators in the classroom. As had been expected with every new emerging technology when introduced into the classroom, the incorporation of multimedia in the classroom changed the landscape of instruction, but it did not make the educator obsolete. Many researchers, while advocating for the integration of multimedia instructional methods in the classroom, also concluded that the use of various multimedia methods of instruction should not be used to replace the human educator, but to supplement and provide additional support for students (Fan & Orey, 2001; Mayer, 2009b; Moreno & Mayer, 1999; Vaughan, 1993). Educators also found solace in the fact that multimedia resources would still need authors and creators. Many of the initial educational videos that were created to support the growth of multimedia were mostly used for Flipped Classrooms and Blended Learning instructional models. Teachers, being the owners of content in the classrooms, found themselves creating multimedia presentations for their own students to supplement their own instruction in the classroom. Their initial contributions to the online archines of educational videos continued to grow as non-traditional educators saw a chance teach something they were passionate about. Knowledgeable people all over the world, through multimedia, became educators as “how-to” and “DIY” videos flooded the internet allowing anyone with an internet connection, a computer, and self-determination, to learn anything they wanted.

The growth of educational videos available on the internet can be attributed to the advancements in accessible high speed internet, non-traditional educators ability to create custom content, and services like You-Tube making the content accessible to anyone with an internet connection as well as giving content creators the ability to make money through advertising revenue (Dreon et al., 2011; Greenberger & Cohen, 2013; Marc, 2009; Roca-

Sales, 2009). The impact of multimedia in the classroom had spilled out and into the homes of non-traditional educators with knowledge to share. With a few clicks, students now have access to educational resources that before were nearly out of reach. Content providers like Khan Academy would eventually receive millions of dollars from corporations like Google and the Bill and Melinda Gates foundation to continue creating content and provide online educational videos on topics beyond the public-school classroom (Thompson, 2011). Eventually over time, the Khan Academy model would evolve from just providing educational videos, to becoming a full-fledged classroom tool that teachers could employ with very little time investment. The new Khan Academy would lead the way for the development of multimedia-based classroom management and instruction systems that would eventually make their way into public-schools all over the nation. Although Khan Academy is seen as a leader in this type of education, there is not much research into the use and effects of these types of educational videos. Researchers van de Sande, Boggess, & Hart-Weber (2013) find that "although Khan Academy (www.khanacademy.org) has published more than 4,000 instructional videos covering K-12 school topics, we do not know (other than anecdotally) how watching these videos translates into learning or resolving student questions." (p. 35). It is crucial that research be developed to investigate this phenomenon and how students are engaging with these videos. While the changes are welcomed by many, opponents of this new approach argue that these systems are simply catering to test-prepping and not preparing students for the rigors of the real-world after formal education (Thompson, 2011). While the multimedia learning approach may not be for every student and educator, it is important to acknowledge the vast impact it has had in and outside the classroom. Research into the effects of multimedia in the classroom continue to show promising results, however, more research should be conducted to fully understand the academic effects technology, in this specific case, multimedia, is having on the teaching and learning process in the mathematics classroom.

Mathematics education pedagogy has undergone many changes since the beginning of public education. With advancements in technology, educational reforms, and drastic changes in the population of students, the modern secondary mathematics educator must be well prepared to engage students with new technology while at the same time, meeting the needs of ELLs in the classroom. As technology becomes more accessible for all students, teachers can employ a variety of strategies and tools to provide the necessary resources students require to achieve content proficiency in preparation for higher level mathematics and/or life after formal mandatory public education. Resources inside the classroom as well as outside the classroom, are just as important. With properly designed worked-example videos, teachers can have at their disposal a resource that most, if not all students, can access with their mobile devices from almost anywhere.

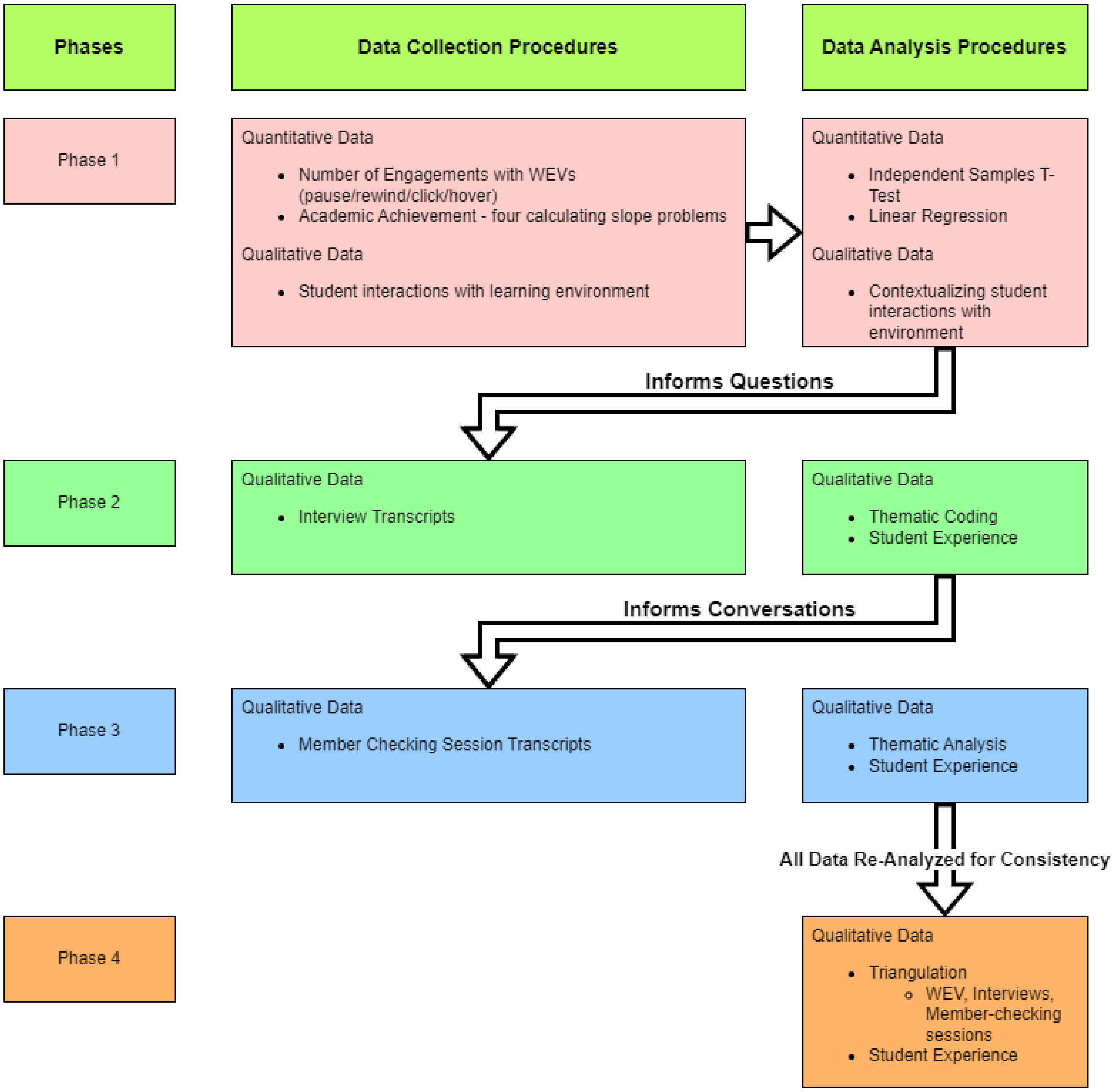
CHAPTER 3

METHODOLOGY

In this chapter, I will discuss the design of the study, including, but not limited to, setting, participants, role of the researcher, how data was collected, analyzed, interpreted, as well as ethical considerations throughout the process.

As explained by Merriam and Tisdel (2015), the data collection process must be supported by the design of the research, as well as the type of data that is collected, be it surveys, interviews, observations, etc. A mixed methods approach was chosen for this study due to the ability to fully capture the experiences students designated as English Language Learners (ELLs) have when engaging with Worked Example Videos (WEVs). While effective research approaches exist in qualitative and quantitative methodologies, mixed-methods provided the best way to provide a rich understanding of the experiences of ELLs. The mixed methods design allows for a deeper understanding which includes generizability, statistical significance, individual experiences, and explores a phenomenon that would otherwise not be sufficiently explored using only quantitative or qualitative methods alone (DeCuir-Gunby & Schutz, 2017). Therefore, this study was designed to have four phases. Below is a diagram of the study design followed by an explanation of each phase.

Figure 2
Multi-Phase Mixed Methods Research Design



The first phase begins with quantitative and qualitative data collection through student submitted self-recording of their screens as they watch their assigned WEV. Quantitative data was collected from four embedded math problems in which students had to calculate the slope of a line given a graph and a line, and subsequently calculate slope given two points in *(x,y)* format. These four problems were then given points using the rubric found in Appendix A measuring student achievement. Student engagement with the assigned video (pause/rewind/mouse hovers/clicks) were also quantified for analysis. Qualitative data was collected in the form of a student self-recording of their computer screen as they engaged with the WEV. These videos were analyzed for all types of interactions, with the video, and non-video elements found in the learning environment. These two data sets influenced the data collection and analysis in the second phase.

This second phase of data collection and analysis involves interviews with participants in which we review their individually recorded video and discuss each of the engagements they may have had with the WEV, their academic achievement, and experience with the WEV. Questions chosen for interviews were informed by the first phase of data collection and analysis. Not all students engaged with their assigned video and thus interview questions varied for each student. The first and second phases of data collection and analysis informed the final phase of data collection.

The third phase of data collection involved member-checking sessions. Two sessions were had with participants in which we discussed their experiences as well as verified coding and generalizable ideas from their interviews as well as their experiences with the videos. Each student was provided with their interview transcripts as well as a list of codes that I found via thematic coding of interviews. These member-checking sessions were transcribed for further analysis.

Finally, the fourth involved a last round of data analysis in which I went through all interview transcripts and member-checking session transcripts to confirm and affirm the experiences expressed by students in each of the phases. Also, with this data in hand, I watched the student submitted videos to affirm their experiences as I found them via thematic coding, as well as how they experienced and explained them in interviews and member-checking sessions.

The four phases of data collection and analysis will provide a richer data set from which to tell the stories of the participants more accurately and ethically as they engage with WEVs. Below is a description of school settings, recruitment process, participant sampling, role of the researcher, the video design process, and lastly the research data collection and analysis methods that were used.

School Settings

The first school selected for this study (referred to as high school A) is a high school in southern California located in a historically working-class Black neighborhood. During the study, the school had a non-white enrollment of 97%, with a student to teacher ratio of 27:1. With 81% of the students approved for Free/Reduced lunch, the school has historically been plagued with below average performance in standardized testing and state benchmarks (Zamora, 2019). This school was participating in a pilot math curriculum during the study and materials were selected in the curriculum that fit the goals and measurable outcomes of the research. The second school selected for this study (referred to as high school B) is a high school in southern Arizona, also located in a historically working-class Black neighborhood. At the time of the study, the school had a 93% non-white enrollment, and a student to teacher ratio of 20:1. This school was not participating in a pilot curriculum, however, all math teachers teaching the same subject (Algebra 1, Geometry, Algebra 2), taught the same materials, same notes, and had the same assessments. This presented a challenge when collecting data for the research from participants. However, the shared curriculum allowed for some teacher freedom and creativity in informal and formal assessments if they were aligned with content standards. Both schools qualified for Title 1 funding and are Hispanic serving institutions while at the same time having the status of being majority-minority institutions with "minority" students making up the majority. In both schools I was the teacher of record for the classes from which participants were recruited. In the next section I discuss the recruitment process. Table 1 below summarizes the key facts from each school site.

Table 1

Participating School Demographic Data

	California High School A	Arizona High School B
Enrollment	1,541	1,497
Free/Reduce Lunch Eligible	1,248	748
English Learner Designated	402	417
Student/Teacher Ratio	27:1	20:1
Non-White Enrollment	97%	93%
Graduation Rate	84%	85%

Recruitment

Participants were recruited from various math classes from grades 9 to 12 over two consecutive academic years. Students were asked to take consent forms to their parents/guardians to allow their data to be used in the study. Although all data collected through classroom activities was actual coursework and part of the class curriculum, students were still required to provide parental/guardian consent to fully participate in the study. Separate consent forms were created for students that participated in the interviews since that process was more extensive and participation required time outside of school hours. A total of 150 students agreed to participate in the study with parental consent by providing strictly quantitative and qualitative data in the first phase. Out of those 150 students that consented to participate, 118 completed all steps and provided data. Steps which were watching the WEVs, attempting to solve the four problems in the videos, and submit a screen recording of their engagement with the video. Of those 118 students, 52 volunteered to participate in phase two individual interviews and phase three member-checking group sessions. Out of those 52 students, 25 were able to return a signed consent form from parents/guardians that allowed them to participate in the second and third phases of the study. The 25 interview participants were not chosen since all participants had the option to participate. The 25 participants were individually interviewed during the second phase, and all participated in one of the two member-checking group sessions. Table 2 summarizes the number of participants in each grade level from each of the schools.

Table 2

Participants by Grade Level

Grade	**Participants from Southern California**	**Participants from Southern Arizona**	**Total**
Phase 1			
9th	25	21	46
10th	16	12	28
11th	15	13	29
12th	9	6	15
Phase 2/3			
9th	5	2	7
10th	4	1	5
11th	6	3	9
12th	2	2	4

Sampling Procedures

According to Creswell & Poth, sampling should support the researcher in selecting participants who are useful in the exploration and answering of the research questions (Creswell & Poth, 2018). Utilizing three considerations, namely, participants, sample size, and sampling strategy, the researcher sets the limitations of the study and then classifies participants who fit within those limitations. Although most, if not all, students have had experience with WEVs through their academic career, not all students are designated as ELLs by the school, and not all students speak Spanish as their home language. It was crucial to have this specific population, as well as others as part of the study, and thus, purposeful sampling was employed. Of the 118 students that agreed to participate in the study, 68 of them had been designated as ELLs and all those 68 students spoke some Spanish at home. It was essential to include this specific population in the first phase, and more so in the second and third phase for the interview and member-checking sessions. Out of the 25 participants in the second and third phases, 15 were designated as ELL. This provided a purposeful sample from which to answer all the research questions.

Role of the Researcher

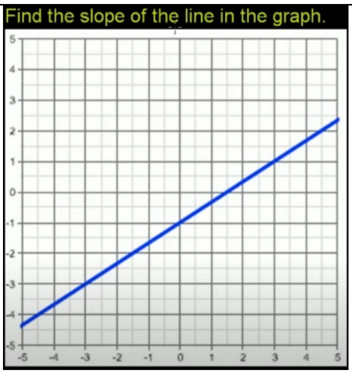
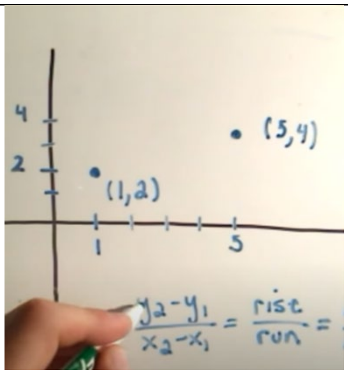
In Mixed-Methods research, the identity and experiences of the researcher influence the collection, analysis, and interpretation of the data (Cresswell, 2014; DeCuir-Gunby & Schutz, 2017; Louis Cohen et al., 2018). In many ways, the researcher must be a "match" with the study. My many identities (researcher, educator, fluent Spanish speaker, designated English Learner in public school, and activist) allow me to bring a multitude of relevant perspectives to this research project. My experience as an educator allows me to pay special attention to details during each phase of this study, specifically the type of content focused on and the ability to have deep conversations with my students during the interview process, which would be difficult for someone that had not cultivated deep meaningful relationships during a school year. As an experienced researcher, I can create questions and processes that will answer the research questions, as well as provide a rich story of student engagement, and teacher pedagogy. As a fluent Spanish speaker, I can switch to Spanish when necessary, with students and/or parents who may need it. This proved crucial as many parents showed early concern and apprehension when presented with this research. All the parents I was able to have a conversation with came to understand the importance of a student-centered and humanizing approach to all pedagogy. As a student that was designated as an ELL throughout public education, I experienced and can relate with the struggles ELL students continue to face today since not much has changed in policy and the way public school educators engage with these students with diverse needs. As an activist, I push for change and allow my students to push as well, to demand what they need, and expect fair, humanizing, and equitable learning practices be employed in all learning spaces.

Video Design Process

The video design process began by finding some of the most popular WEVs on the Internet, as well as those used by state curriculums (CA/AZ), and lastly videos most shared via the popular TeachersPayTeachers website. Through a rigorous search using terms "calculating slope," "math help," and "worked example," Khan Academy showed the most views with over 2 billion views across its platform. YouTube had several popular channels, @patrickJMT with 1.33 million subscribers and several videos with more than 4 million views each, followed by @blackpenredpen with 1.02 million subscribers and several videos with 5 million views or more. Lastly, searching on TeachersPayTeachers platform, the most common lesson resources included some videos (mostly from Khan Academy and some from YouTube) which were created by the two channels mentioned above. A total of five (5) videos on calculating slope were selected from the sources mentioned above. The video URLs can be found in Appendix B.

Using literature from meta meta-analysis by Noetel et al. (2022) in which they identified the best multimedia design strategies to reduce or manage cognitive load, each of the five videos were analyzed to find elements that increase cognitive load as well as elements that decrease cognitive load. None of the videos automatically included a significant element of cognitive load reduction, namely captioning for second language learners, unless enabled through the settings for the video. Noetel et al. (2022) explain that "captioning led to large benefits for both comprehension and vocabulary acquisition" (p.

32). All three videos by Khan Academy were very similar. The medium used was a black background with writing displayed in different colors on it as it was narrated, with the "writing cursor" always moving, providing some animation. According to findings by Berney & Bétrancourt (2016) and Höffler & Leutner (2007), animations tend to yield better outcomes at facilitating learning when compared to static images. Although the videos do not employ graphical animations, the moving cursor and active writing does provide some animation which may lead to higher engagement as viewers follow along. Researchers find that "studying with animation when learning dynamic phenomena is beneficial compared to static graphic display" (Berney & Bétrancourt, 2016). One of the Khan Academy videos and the @patrickJMT video used a static image of a graph, one with a line and the other with points, which help in reducing cognitive load and lead to better learning since they are presenting certain mathematical information as a graphical display. Figure one and figure two show these two graphics as seen on the videos.

<table>
<tr>
<td>
Figure 3</td>
<td>
Figure 4</td>
</tr>
<tr>
<td colspan="2">Figure 3 is from a Khan Academy video displaying a static graph. Figure 4 is from YouTuber @patrickJMT which shows a hand drawn graph.</td>
</tr>
</table>

Grounded in visual argument theories of graphical processing and relating, researcher Ioanna Vekiri (2002) claims that "graphical displays are more effective in communicating data relations, trends, and patterns" (p. 263). Since the content students were learning in this research was calculation of slope given two points on the X and Y coordinate system, which is the relationship between change in y over change in x, a graphical display would be necessary and beneficial in the intervention videos.

While the visual aspect of multimedia learning is important, the audio aspect requires attention as well. None of the videos chosen had music or extraneous sounds, which have been found by several studies to be a distraction from learning. Mayer & Moreno (2010) explain music as part of 'seductive details' and not helpful for learning. In their study, they explain "students performed better on retention and transfer tests when the lessons did not have extraneous sounds and that students' learning was hurt the most when both music and environmental sounds were combined" (Mayer & Moreno, p. 137). Another study by Moreno & Mayer (2000), had similar findings that students who listened to music while studying had lower content retention. They found that "students remembered significantly less verbal material when music had been presented" (p. 120). Thus, the five videos used in this study did not actively increase the amount of cognitive load by including music or extraneous sounds, which should lead to better content retention.

Another important aspect of WEVs and cognitive load management is the ability for the user to manage their own cognitive load. Citing a study by Mayer & Moreno (2010), Noetel et al. (2022) tell us "If learners can pause, rewind, or re-read content, then they can somewhat manage their own cognitive load by taking things more slowly if they are overwhelmed" (p. 15). Although with all WEVs, the user has that ability, some videos explicitly ask the user to pause the video to focus on a task, read the content on the screen for deeper understanding, or answer questions related to the content being learned. This type of cognitive load management should ideally be included in the design process and not left up to the user to self-regulate if there are opportunities in the videos in which students would benefit from pausing the video or rewinding.

With several design elements in mind to reduce and manage cognitive load, the intervention worked example videos were created. The created videos included instructions for students to turn on the close captions that I wrote and incorporated into the video. They also included some animation via the moving cursor and written words, as the math work was done. Although research has shown that music is detrimental for student learning and content retention when watching worked example videos, in my classroom, students often listen to music while working on individual assignments or taking assessments. Due to this knowledge, I decided to include music picked by the students in the intervention videos. I believe the addition of music is not something that should be done for all WEVs, only in this specific instance with this specific population. The videos also included instructions so that students would understand that they could pause, rewind, and re-watch any portion of the video as they saw fit, as well as places in which the video automatically stopped so they could answer questions. I also used a graph to represent the relationship between rise and run for slope. The video also employed the strategy to replace text with audio in much of the video. According to Ginns (2005), presenting information as audio versus visual text, reduces cognitive load and improves knowledge transfer. The type of language used throughout the videos is conversational, which increases friendliness and improves cognitive processing of information Ginns et al. (2013). I believe the voice they were hearing being the voice of their teacher since the beginning of the school year, a voice of someone they've learned to trust and know cares about them and their success, will also be valuable. Lastly, key words on screen were coupled with audio. By presenting a visual representation of a key word with the audio, these WEVs create redundancy which leads to better learning outcomes and language fluency, which is something we look to support for students designated as ELLs (Adesope & Nesbit, 2012).

Data Collection

Data collected throughout the study began with general school demographic data provided by the National Center for Educational Statistics. Participant demographic data such as age, gender, living situation, household income, family structure, and home were used throughout the study and were collected via questionnaires in the classroom from consenting participants as well as data from the schools and respective districts. Although not all data collected was used in this study, it can be used for further analyses in future studies. Qualitative demographic data collected here will be used to provide context for participant experiences.

The first phase of data collection begins with student-submitted recording of their individual screen as they engage with WEVs. Participants were given one of four different videos during the study. They first choose English or Spanish as the language for the video. This choice only mattered in the language of the questions presented and some of the language in the video. Next, they were randomly assigned the intervention video that was specifically designed with the cognitive load reducing strategies, or a control video from YouTube or Khan Academy that worked through an example in calculating slope. This created four different possible combinations for video assignment, English Control/English Intervention and Spanish Control/Spanish Intervention. The videos contained four slope questions which students had to answer to the best of their ability. Scores were given according to the rubric found in Appendix A. Videos also provided the number of times students engaged with the video. The four categories created by video type and language will be useful in quantitative data analysis when comparing groups and answering the second and fourth research questions; “How do students’ Mathematics performance change before and after watching a Worked Example Video?” and “How effective are newly designed illustrated Worked Example Videos for ELL’s and other student populations?”.

The second phase of data collection is recorded individual interviews with participants. These recorded interviews included conversations about their specific submitted recordings, questions about engagement with the video, and engagement with their environments. Also questions about the videos they watched, and their thoughts about various elements of media and media design. During interviews, students were provided with their scores on the math problems as well as the rubric that was used, which were also discussed.

The third phase of data collection is recorded member-checking group sessions. These sessions served as the second round in code analysis. Saldaña (2021) does a great job in explaining that coding requires several rounds to truly engage with data deeply. During this third phase, students and I discussed codes found in interviews, as well as their individual experiences with WEVs, thoughts, emotions, and opinions were all freely shared.

These interviews and group sessions were conducted via zoom due to the Covid-19 epidemic limiting in person interactions. A template of possible interview protocol can be found in Appendix C. This pool of questions was designed to prompt students to describe their experiences when engaging with WEVs in order to understand and create a rich contextual story. It is important to note that while this phase in data collection was intended to be quite somewhat formal, as students became comfortable in the question-and-answer process, the interviews and sessions became more of a conversation, close to what some critical communication scholars employ as ‘platicas’. Formal interviews and member-checking sessions in which traditionally the interviewer decides the topics shifted dramatically. As scholars Michael Tristano Jr. and Ana Isabel Terminel Iberri state, “Rather than me deciding what we would talk about and how our discussions would look, we made these decisions together” (Tristano & Terminel Iberri, 2022, p. 8). This very apparent shift in communication style is important due to the power dynamics at play found in formal educational spaces, compared to the informal, and sometimes more communal power dynamics found in other methodologies. Interview and member-checking session data was crucial in answering the four research questions since context allows for deeper understanding.

Part of the data collection process was developing and choosing which questions to ask students, based on their engagement with the WEVs and performance on the four math questions. Students who struggled with all four questions were not asked questions about math content and solution processes and instead questions about their thought process, engagement with the video, and the content/strategies of the video. Students who were able to answer all questions, correctly or not, were asked questions about their thought processes, answers provided, how they arrived at those answers, as well as content/strategies of the videos. Students who answered all questions relatively correct, were asked about their solutions processes, their thought processes as they solved, engagement with the video, as well as content/strategies of the videos. Since only 25 of the participants agreed to be interviewed, not all perspectives could be included. However, all the variations of populations and video combinations were represented in the interview participants. Data collected via interviews included, but was not limited to, participant confidence as they worked through the problems and watched the videos, reasons for the various types of engagements with the video (pause/rewind/play/mouse movement), awareness of cognitive load, challenging parts, difficulties, previous knowledge, and other types of data that would help inform and create a rich narrative of their experiences. Interviews and member-checking sessions were audio-recorded and transcribed for analysis.

Data Analysis

Data was analyzed in four separate phases throughout this embedded mixed-methods study. The study used an embedded-experimental mixed methods strategy (Creswell & Plano Clark, 2017; DeCuir-Gunby & Schutz, 2017; Teddlie & Tashakkori, 2009). Quantitative data (number of engagements) and qualitative data (reasons for engagement) were collected from student submitted videos and analyzed to inform individual interviews. Individual interviews produced themes (Saldaña, 2021) that were then embedded in questions during member-checking group sessions. Member-checking sessions were analyzed and triangulated with original videos and individual interviews (Turner et al., 2017) providing an accurate student experience as well as a better understanding of the intervention than either approach alone.

The first phase in analysis includes a dependent samples T-test, and a simple linear regression. The dependent samples T-test will compare math scores between control group and experimental group. As explained by Louis Cohen et al. (2018), "The t- test is used to discover whether there are statistically significant differences between the means of two groups " (p. 777). The Spanish/English difference will not be investigated since not enough students chose the videos in Spanish.

Next, a simple linear regression analysis was done with dependent variable being scores earned through solving problems, and independent variable being quantified engagement with videos. Louis Cohen et al (2018), as well as Cohen & Holiday (1996) explain how simple linear regression allows researchers to predict the value of one variable when the value of another variable is known. This regression will help the students and I understand how student engagement with the WEVs via pauses, rewinds, fast forwards, mouse hovers, and mouse clicks had any effect on student outcome in solving the problems.

Lastly, the student submitted videos will be analyzed for student interactions with their environments. While this was not planned in the research design, during analysis of the videos, students were interacting with their parents and siblings. These interactions needed to be included in analysis as distractions play an important role in student learning and retention. This first phase in analysis will help answer the second and fourth questions as well as inform the second phase of data analysis.

The second phase of data analysis begins with qualitative analysis of transcribed interviews. Interviews received a thematic analysis process and triangulated (Denzin, 2001) using student submitted videos as well as member checking from participants in the third phase. For this second phase of analysis, I did open descriptive coding (Saldaña, 2021) with interview transcripts, which allowed me to understand some general codes that were shared between students while engaging with WEVs. This produced over 100 varying codes amongst the students which relate to the research questions. Out of these 100 codes, the students and I were able to arrive at a consensus for the top 10 codes. These 10 codes were chosen for discussion with participants during the third phase of data collection.

The third phase of data analysis was member-checking (Patton, 2014; Saldaña, 2021) with students about what emerged during the first and second phase of data collection and analysis. I was able to meet with all the interview participants via zoom to have conversations about the 100 preliminary codes. Of the 25 that participated in interviews, 19 were able to join the first zoom session, and a second zoom session was held which the rest of the interview participants were able to join. I explained to the participants the purpose of the session, to ensure the stories and themes I was finding were accurate as they saw them and experienced them. Each of the students had an opportunity to review their individual interview transcript and change anything they thought needed changing, as well as suggest codes I may not have seen. We engaged in conversations about WEVs and their experiences and some even gave recommendations on how to improve them for themselves and perhaps other students.

For example, one of the suggestions some of them had was to include pauses in videos that allow students to either copy down material or try out a problem. Some of them expressed a sense of anxiety trying to keep up with videos as they struggle to write things down. Once one of the students brought this to my attention, several others shared their agreement with their ideas and even connected it to similar experiences in the classroom, where they also struggle to keep up with note taking. At the end of the zoom sessions, students were excited about their voices and ideas being part of research and they even mentioned the idea of changes in classrooms and other videos online. The collaborative process provided a humanizing way to approach research as well as ensuring student voices were truthfully represented.

The fourth phase of analysis merged the first, second, and third phases together to create a more definitive version of emerging themes as well as student experience. At this point I was able to incorporate the ideas students had during member-checking as well as initial themes that were found during the first phase of coding. While many of these themes overlapped, some were new and made a great addition to the findings. These themes that emerged from the first and second phases, combined with member-checking sessions with the participants allowed us to create a rich story of student engagement and disengagement with WEVs. At this time, I then re-watched all the student-submitted videos and began to affirm the collaborative findings as they emerge from the videos as explained by students during the member-checking process. This last phase was instrumental in affirming the experiences from both me and the participants.

Finally, as part of the analysis I will provide a narrative detailing the findings of this research, but more importantly, the experiences of the students, centering their voices in this research. This narrative will include thoughts on worked example videos, ideas on improving videos, as well as possibility of future research.

CHAPTER 4

ANALYSIS AND FINDINGS

In this chapter, I discuss the research findings related to each of the questions and provide a rich story of the student experience while engaging with worked-example videos. The first research question; "How and why are students engaging with worked example videos?" was explored through interviews with students as well as a collaborative process with participants in which we review their self-recorded videos as they interact with worked-example videos (WEVs). Students that participated in the interview phase of the research were interviewed via zoom due to Covid-19 global pandemic, which began in December of 2019. Effects of the pandemic, which some argue has not ended, are still being felt as well as cases of "long-covid" for large parts of the population (Fisher et al., 2022; Hatzikidi, 2020; Saputri et al., 2021). While new protocols for interviews made the process challenging, it also provided students an interesting opportunity to engage with their own videos and explore their own understandings of their engagement with the WEVs.

The second research question, "How do students' Mathematics performance change before and after watching a Worked Example Video?" is explored through both quantitative and qualitative data analysis. A simple linear regression, combined with the member-checking and interview process provided deep insight into how students experienced their own performance in calculating slope, as well as personal experiences navigating, what some explained as, "stuff I do not know."

The third research question, "What are the specific experiences of ELLs as they watch worked-example videos as part of their mathematics learning process?" allows participants to share their unfiltered experiences when watching WEVs as part of learning and instruction. Interviews and member-checking phases of the study provide a rich data set from which we (participants and I) can tell a rich and candid student-centered story.

The final research question, "How effective are newly designed illustrated Worked Example Videos for ELL's and other student populations?" relies heavily on quantitative analysis for generalization as well as interviews with participants. While a dependent samples T-test can show us some statistical significance, the participant experiences and feelings of learning also helps us understand how these differences in multimedia design require more exploration.

Research Question 1: Student Engagement

Student engagement was explored through individual interviews and member-checking sessions. Interviews were open coded (Saldaña, 2021) with general themes emerging from conversations. Although over 50 unique codes/themes emerged from the first phase of data analysis, after member-checking and talking with students about their engagement, we collaboratively found that the top 10 codes would provide the richest story of their experiences and decided to focus on these codes during the third and fourth phase of analysis. It is important to note that in all 25 individual interviews conducted, each of these 10 codes emerged in some form. The thematic open coding led to some interesting conversations with participants during the member-checking phase of the analysis. In this next section I share some specific insights about some of the codes, the importance of each code in the experiences of students, and implications for WEVs. The top 10 codes/themes are shown in Table 3 below, along with the frequency.

Table 3

Top 10 Thematic Codes and Frequency

Code/Theme	Description	Frequency
Arithmetic	Students talking through arithmetic, mathematic steps and calculations, thinking out loud, etc.	243
Video	Anything having to do with the video itself, content, sounds, images, etc.	147
Difficulty	Student expressed some level of difficulty when viewing the problems in the video ("this is hard", "this is kinda easy")	137
Knowledge	Students shared lack or presence of knowledge ("I don't know this", "oh I know this")	124
Procedures	Students talked about having to follow some sort of procedure or linear steps towards a solution ("next I'm supposed to…")	84
Emotions	Students sharing emotions of not being good enough, talking negatively about themselves, proud of themselves, joy, anxiety, etc.	81
Notes	Students mentioning copying something down from the video or an idea they had while watching the video	78
Slope Formula	Discussion about the formal "rise/run" formula for slope, also change of y over change of x, and y=mx+b	67
Fractions	Knowledge of the necessity of fractions when working with slope	49
Prior Knowledge	Students talking about something they remembered from a lesson in a class, not always our current class	48

The first code "arithmetic" was the most common code, and it included anything having to do with the mathematical aspect of engaging with the video. While not all students mentioned specific steps they were taking when solving problems, all included some sort of mathematical language, which is an expectation from the Common Core State Standards (Coggins et al., 2007; O. Lee et al., 2013; Moschkovich, 2005; Walqui & Heritage, 2012). Below are some transcript portions that demonstrate how students used mathematical language and explained their experience engaging with WEVs. (initials used for students to protect their identity)

> **RRR**: “here you answered ‘change of y over change of x’, what does that mean?”
> **GH**: “so I remembered that **slope** is a **fraction** and there was a song that we learned last year about slope”
> **RRR**: “ok, got it (laughs) do you remember the song?”
> **GH**: “nah but it was basic as fuck”
> (we both laugh)
> **RRR**: (still laughing) “ok, I remember I made a song about the quadratic formula to Wrecking Ball by Miley Cyrus, I’ll play it for you one day, its lame too. Ok so you wrote ‘change of y’, what does that mean in this problem?”
> **GH**: “I think its how the first y changes to the other one, and I’m sposed to **add** it or **subtract** it, see I was finna see if the video showed it so I went back”
>
> **RRR**: “what does this little triangle mean?”
> **LA**: “no cap, I don’t even know, I just know we supposed to write it”
> **RRR**: “yeah I don’t even know what its for either, math is weird. (we both laugh) but it means ‘change’, you remember anything about that?”
> **LA**: (thinks, looks at video) “I think it has to do with **subtraction**, but tbh I cant really remember”
>
> **RRR**: “ok so explain to me what this means here?”
> (points to fraction as part of student answer)
> **JR**: “so **slope** is **change of y over change of x**, basically you **subtract** the y’s and x’s from each other”
> **RRR**: “yes, thank you, what did you do next?”
> **JR**: “ok so I wrote that, and I **subtracted** and I got that as the **slope**, and I cant **simplify** it cuz the numbers are different or whatever”
> **RRR**: “good job! Good explanation too!”

The varying degrees of mathematical knowledge consistently changed from student to student, however all of them were able to include some mathematical language in their explanations. As national standards like Common Core become policy and as policy continues to change, students are caught having to learn and re-learn how to be students whenever there are policy changes. As can be seen from the transcript excerpts, students are employing mathematical language even if they are lacking the procedural knowledge of solving the problem, nor meaning of the words they are using. It’s important to note that the WEVs students watched did include much of the language used by students during interviews, which may have had some effect in the widespread usage by all students, however, I suspect students were able to effectively employ such language because it is something they practice in the classroom. Many students, when asked about specific mathematical language, mentioned having to learn specific words in class, writing them down, and teachers asking them to use specific words. One student explained "Mr. *** always corrects me and tells me to use these dumb math words, like I know what subtract is but take away means the same thing". Another student shared "sometimes I don't want to raise my hand because I don't use the words the teacher uses so I feel dumb".

The second code, Video, was useful in learning what students liked or disliked about the WEVs and what they believed would have made the videos better. All students were asked "What did you like or dislike about the video?" and "What would you keep or change about the video?". Below are some responses from students after those two questions.

> **HR**: "the man worked too fast and I couldn't write fast enough, he needs to slow down"
> **JT**: "music was cool but you should have had DaBaby on this"
> **PM**: "I liked how we could see the writing happening"
> **RS**: "I would probably put some memes on here"
> **LE**: "dead ass, I liked the video because it helped me see the steps better"
> **AH**: "I think if it had the steps written out, I would understand it better"
> **JH**: "I liked the arrows, they really helped to understand where to put numbers for the fractions"

Overall students shared that they liked that the videos went step by step. This is something almost every student commented on, sharing that it was very helpful for them to see steps worked out. Some students suggested that with each step, there be written instructions that explain the step. One student specifically said "for me, it helps when I can see why I have to do a step. I need to understand the reason". As an educator, I stress the importance of always having a reason for the things you do, not just in the mathematics classroom, but also outside the classroom. When asked about this perhaps being part of future videos during member-checking, almost all students agreed that it would be beneficial for them as well. Most students liked the fact that they could stop the video, which they cannot do in class when the teacher is presenting problems. Students felt that by being able to stop the video, and rewind when they needed, they were able to have more control and copy down things at their own pace. Eight different students shared the sentiment that they did not feel rushed, "I liked that I could pause it to stop and copy things down. I can't do that in class". While control of the video was a feature that most students shared was beneficial, many also said that not being able to ask questions was difficult. When this came up during the member-checking portion of the research, one student suggested having a Frequently Asked Questions (FAQ) for videos which could offer students with often needed support, as well as giving students a chance to share their experiences in the form of questions that could help future students navigate the same difficulties.

The next two codes "difficulty" and "knowledge" have a lot of overlap and students often shared experiences with them together. As students shared the difficulty of what was being asked of them, that difficulty was often grounded on what they did not know or remember at that point in time. Below is one such conversation I had with one student, which reflects other similar conversations I had with most of the students.

> **RRR**: "so you stopped it and went back, do you remember why?"
> **JP**: "this question is just like the one in the video but it's harder"
> **RRR**: "what makes this question harder?"
> **JP**: "because I don't know how to get the fraction"
> **RRR**: "so you know you have to use a fraction?"
> **JP**: "yeah but fractions are hard cause I don't remember a lot of it"
> **RRR**: "I get that, fractions are hard, they are hard for me too, it's a lot remember"
> **JP**: "if I knew more about fractions, it would be easy"
> **RRR:** "do you know if the video had fractions earlier?"
> **JP**: "I think it did, I think that's why I stopped it and went back, to check"

This short conversation continued as I asked probing questions and the student eventually remembered what they had to do to solve the problem, the steps. Some students had a similar experience in that they were able to figure out what steps they needed to take, while others were not able to arrive at the same conclusions or quite possibly simply did not know. The emergence of these two codes in all interviews tells us very compellingly that students are having these struggles when engaging with remedial and/or instructional multimedia. It is imperative that design principles for this type of media consider the need for supportive strategies to better support students and not only procedural knowledge.

The next code, procedures, tells us that students are actively thinking about steps and what they should do next. They are understanding the problem or task at hand requires specific steps to solve. Previous research (Rittle-Johnson & Siegler, 1998) has focused on this “knowledge of sequences of steps or actions that can be used to solve problems” (Crooks & Alibali, 2014). In recent years, there has been a shift in research from procedural knowledge to conceptual knowledge (Atkinson et al., 2000; Bishop & Verleger, 2013; Chappell & Killpatrick, 2003; Riley et al., 1984). Dr. James Greeno, one of the leading researchers in the field of educational psychology, has been pushing forth the importance and value of procedural knowledge for some time, Greeno (1978). The emergence of this code during student interviews tells us that students are still focusing on procedures, even though research suggests that conceptual knowledge and instruction is far more effective in developing student understanding (Crooks & Alibali, 2014; Star et al., 2005). For students that were able to successfully complete all the problems, when asked about their experience in solving, all mentioned *knowing* the steps to solve, and none of them mentioned conceptual knowledge about slope, slope being rate of change, or the connection from rate of change to the concept of change of y over change of x. All of which are considered conceptual connections.

Students shared the emotions they felt when engaging with WEVs without being prompted. Interview protocols were not designed to elicit responses about emotions, yet students felt it was necessary to speak about their emotions as they navigated this particular learning space. Researcher Yadav provides a great description on the impact of negative emotion on student learning, "Negative emotions draw student's attention away from the task at hand. Anxiety of failure can make a student anxious and frustrated leading to reduced attention on task" (2018, p. 1646). Students that struggled in answering questions shared feelings of disappointment and anxiety as they struggled to figure out what they should be doing to calculate slope. Students that successfully completed one or more problems shared feelings of accomplishment, joy, and confidence. During member-checking, students were asked to share more about the emotions they felt. Here is one excerpt from the member-checking transcripts followed by two excerpts from individual interviews. These excerpts show that students are recognizing their emotions as they engage with WEVs, and the impact emotions have on their ability to find success when working through problems.

> **RRR**: "everyone talked about emotions during interviews, lets talk about them"
> **JP**: "I don't know about yall but I feel dumb a lot in class"
> **JT**: "yeah, no cap, I feel stupid a lot too, and Ms *** don't help"
> **PM**: "yeah she be telling me I should know stuff but I don't know it and doesn't help me at all"
> **RRR**: "ok, so let's come back because I don't want this to be a bashing teacher session"
> *students laugh*
> **RRR**: "so some of you shared feeling anxiety when working on the problems in the videos"
> **JP**: "ok so when I was doing the video, I saw other people working but I didn't know what to do and that made me feel anxious"
> **RJ**: "I'm the same way, I think I should know cause other people know but when I don't I feel dumb"
> **PA**: "usually when I know that we learned something in class, and I can't remember,

> I start to feel anxious. Then if I can't remember, it gets worse and then I just give up"
> *many students nod in agreement*

The conversation initially began as a "teacher bashing" session, which I was able to redirect back to the topic. While that is not a focal point of this research, it is important to note the impact teachers have on students when students don't feel supported. Two individual interview transcripts are below also showing student emotion when engaging with WEVs.

> **RRR**: "so you were able to answer all the questions. You paused the video here, can you tell me why?"
> **LD**: "yeah so I saw the formula for slope so I paused the video and wrote it down"
> **RRR**: "why copy it down?"
> **LD**: "I know we learned it in class, and I remember we copied it down too"
> **RRR**: "nice, ok. You didn't pause it again and you submitted your answer, how did you get that?"
> **LD**: "once I had the formula, I knew I could solve it cause I had done this before and i didn't have any doubts so I felt good I had the right answer"
> **RRR**: "ok thank you, turns out you did in fact have the right answer, good job!"
> **LD**: "oh really? No cap, I knew it Mr. R"
>
> **RRR**: "so you were able to finish the video and solved all the problems. You paused the video a few times, 5 to be exact. Why were you pausing it?"
> **JP**: "I was taking notes of the problem in the video"
> **RRR**: "ok, do you always take notes?"
> **JP**: "yeah pretty much, I cant memorize everything so notes help"
> **RRR**: "yeah, I agree, good, were they useful when you were solving?"
> **JP**: "oh yeah, the problem was the same, just different numbers so I was really happy I had the notes"
> **RRR**: "yeah, I'd say it was a good choice since you got that problem correct"
> **JP**: "yaaaay"

These excerpts from the member-checking sessions as well as the individual interviews show that students are very much feeling and naming these emotions as they engage WEVs. Design principles for multi-media in the classroom do not account for the feelings of students (Ambron & Hooper, 1988; Drijvers et al., 2009; Greher, 2004; Leow & Neo, 2014), which as we can see from interviews and member-checking, directly impact student achievement. Research shows that when student experience positive emotions during learning and instruction, retention increases, as well as student achievement (Oades-Sese et al., 2014; Pekrun, 2014; Yadav, 2018).

The next code, notes, would make teachers proud because it is something that is structural to most all public educational strategies. Students mentioned taking notes as they watched the video. This is something that is taught to students in all math classes, as notes are their own reference for concepts, big and small ideas, and procedures in solving math problems. When asked about this during member-checking phase, many students shared that they've always been told to copy things down, even if they don't know what it means. When asked what they do with notes they copy, many students stated that they do nothing. Many stated that they only took notes because teachers checked notebooks, and not because they could use them as a tool for problem solving. Interviews and member-checking showed students lacked the training required to utilize their notes when solving problems as well as understanding the actual notes as they copied them. When asked about the notes they copied while watching WEVs, most students did share they were able to use them since the problems were very similar. I explained that they were in fact identical with different numbers. Some students realized this fact and were able to successfully use their notes.

The last three codes, slope formula, fractions, and prior knowledge always appeared together. Students shared how they knew they were supposed to use the slope formula, how it was a fraction, and how they knew they had been taught the formula specifically. Students talking about prior knowledge, something teachers are expected to focus on and utilize for all students in the classroom, is a positive highlight in that students and teachers are both thinking about what students should/might know from previous classes.

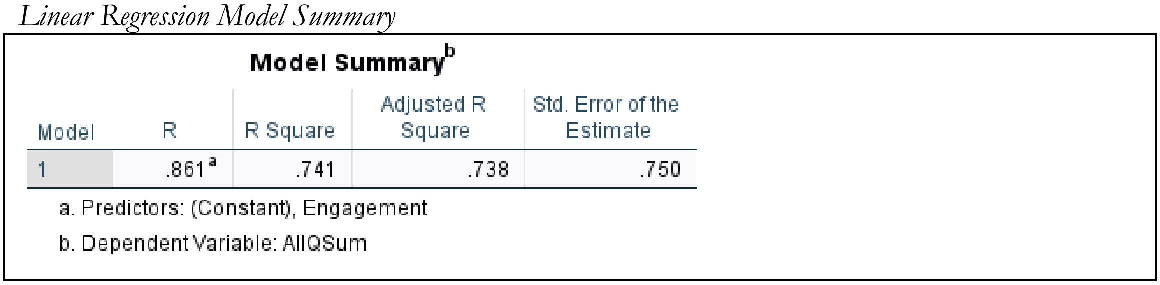
The coding of the interviews and subsequent member-checking phase presents an in-depth view of the student experience when engaging with WEVs. Students are thinking about slope formula, and fractions, and steps to solve, many of the things they are learning in the classroom. However, it also shows that students are still lacking conceptual knowledge in how to apply different strategies and problem-solving methods that are not as rigorously focused on in the classroom. Students are also struggling to manage emotions that are ignored by design principles for multimedia.

Research Question 2: Student Achievement

A simple linear regression was applied to understand if there was any type of predictability between the number of engagements (independent variable) with WEVs and problem-solving achievement (dependent variable). Table 4 below shows the linear regression model summary output followed by its analysis.

Table 4

Linear Regression Model Summary



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.861[a]	.741	.738	.750

a. Predictors: (Constant), Engagement

b. Dependent Variable: AllQSum

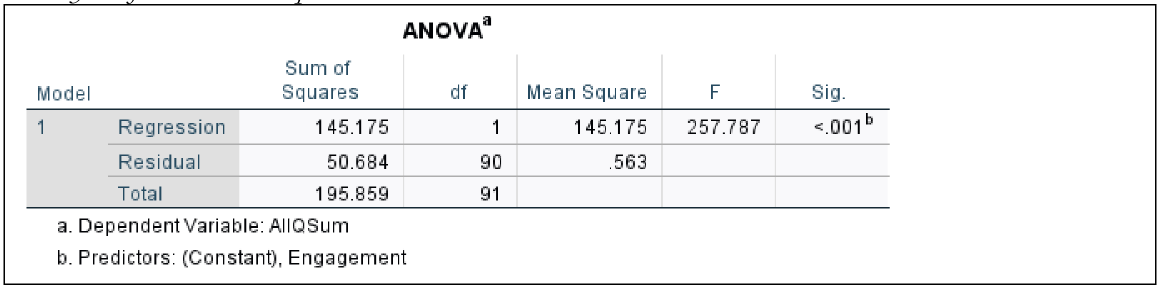
The model shows a strong correlation between the number of engagements with WEVs, and academic performance calculated by the sum of points earned on all questions throughout the WEV. Engagements were calculated from student submitted recordings of student screens while watching an assigned WEV. Each pause, click, rewind, fast-forward, and mouse hovers were counted as an engagement. Students earned points by answering four questions through their assigned WEV. The sum of all these points is the predictable value.

Student achievement was found to be positively related to student engagement with WEVs, r(92) = .861, p<.001, which is considered to be a strong relationship (Creswell, 2012; Teddlie & Tashakkori, 2009) with the number of engagements accounting for 74.1% of the variability in academic achievement measures. This strong relationship shows us that as a student engages with a WEV, they increase their chances of performing well in answering questions. More research would be needed to investigate if retention is happening from engagements with WEVs.

Linear regression provides a prediction model for engagements, and student performance on math questions in WEVs. Table 5 and 6 below are the output tables for the analysis of variance and regression coefficients, followed by analysis and discussion.

Table 5

Analysis of Variance Output Table



ANOVA[a]

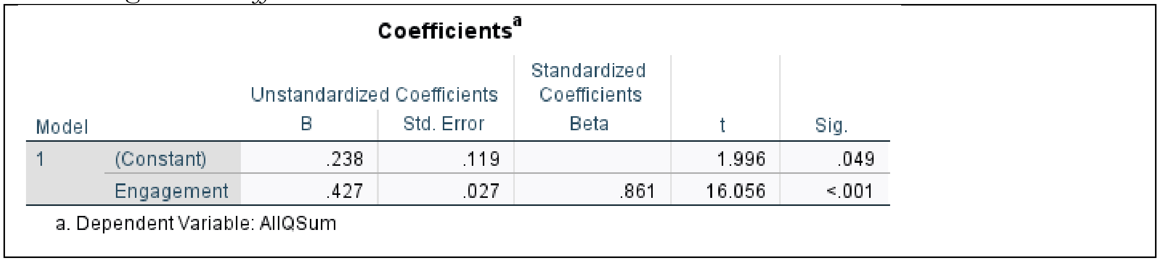
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	145.175	1	145.175	257.787	<.001[b]
	Residual	50.684	90	.563		
	Total	195.859	91			

a. Dependent Variable: AllQSum

b. Predictors: (Constant), Engagement

Table 6

Linear Regression Coefficients



Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	.238	.119		1.996	.049
	Engagement	.427	.027	.861	16.056	<.001

a. Dependent Variable: AllQSum

A simple univariate linear regression was conducted to evaluate the prediction of student academic performance in four slope calculation problems from the number of engagements the student had with the WEV. The linear combination of engagements and academic performance was statistically significant F(1, 90) = 257.78, p<.001. This model tells us that every time a student engages with the WEV, their academic performance could increase by .427. This strong positive correlation/predictability affirms the importance of understanding why students are engaging with WEVs, and how can WEVs be designed to maximize each engagement.

When comparing students that were assigned the control videos, versus students that were assigned experimental videos, academic achievement scores were higher for students that were assigned the experimental videos. An independent sample one-tailed t-test was conducted to determine if control group (*M*=1.35, *SD*=1.429) academic performance differed from the experimental group (*M*=1.98, *SD*=1.45). The Levene's test for equality of variances was not significant (F=0.747, p>0.05), so equality of variances can be assumed. There was a statistically significant difference between academic achievement between the two groups, experimental group showing a larger increase t(90)=-2.096, p<0.05. These findings show that the purposefully designed WEV had some impact in student achievement. Further research is needed to identify specific elements that had the most impact.

Research Question 3: Student Experiences

To understand the specific experiences of students designated as English Language Learners (ELLs) as they watched worked-example videos (WEVs), interviews data, analysis of student submitted videos, and member-checking sessions led to a rich data set from which to construct a rich narrative. The many unique experiences of participants must be analyzed within the context of what was happening in the world at that time. “School” was very different due to the Covid-19 pandemic. There was no in person instruction and students were expected to suddenly self-motivate to complete assignments remotely, manage their time at home with family, suddenly manage family relationships while learning at home, and other unexpected responsibilities.

As I analyzed the videos students submitted, I was transported to the many homes the students live in. I heard mothers in the background communicating with students; “tienes hambre?”, “bajale el volumen”, “vengo ahorita, “vela tu hermana”, and other things madres tell their children. Siblings arguing with each other, playing games, and pets in the background provided a brand-new and unexpected learning landscape. This was a unique experience because these students and parents had never been through a pandemic and had never had to stay home for a prolonged period, learning, studying, and managing household routines. It was apparent that as students attempted to watch these videos, they were also facing multiple distractions. When asked about distractions during member-checking, many students expressed frustration and shared how they often argued with parents or siblings as they attempted to set boundaries to protect their learning space. During member-checking sessions, students realized that they, along with their parents, were both ill-equipped to manage this new learning space. Below is an excerpt from one of the member-checking sessions in which we all explored this new dynamic.

> **RRR**: “ok let’s talk about remote learning”
> **PM**: “I hated it”
> **JT**: “same”
> **PM**: “dead ass, my sister is so annoying”
> **RRR**: “yeah so lets talk about siblings, I noticed in the videos a lot of different voices”
> **HA**: “yeah we were all home, on our computers and I couldn’t really study”
> **JP**: “my brother didn’t have a laptop so my mom made me share”

> **RJ**: "we don't have internet at home so I kept having to use my phone hotspot and my dad got mad cause I used all the data"
> **PA**: "omg yes me too!"

This short excerpt shows some of the various distractions and difficulties students were facing, many times without support from the school, a school that was also ill-prepared for this new situation. While not specifically measured through formal research strategies, it is safe to state that all these extraneous distractions added to the cognitive load of students. As they shared their experiences during interviews and member-checking sessions, it was obvious that many of them were overwhelmed, or experiencing cognitive overload, as they attempted to engage with the WEVs. This is an important limitation of the study, one that was impossible to account or plan for, due to the Covid-19 pandemic and shift to remote learning.

When asked about their experiences with the WEVs specifically during interviews and member-checking, students articulated specific things they thought were helpful in the videos and things they did not find helpful, or as they articulated, "dumb". Students shared that videos they've watched before did not have questions and were simply just videos with problems and solutions. Many shared that having problems to practice in the videos was good, and that they wished the video showed if they answered correctly. Instant and useful feedback is an important aspect of teaching and learning in the classroom (Adams et al., 2014; Braun et al., 2014; Fisher & Frey, 2013; Fyfe et al., 2012), thus transferring this strategy to instructional media makes sense.

Students also shared that they wished videos included more vocabulary and definitions. We saw from interviews that students did not make conceptual connections between slope, fractions, and change of y over change of x. When asked about how language support would be useful, students shared that they just did not know what the word slope meant in the context of the problem. A discussion about language support during member-checking provided important insight into how instructional media lacks the language supports ELLs depend on and leads to academic success. Research has shown that language support not only helps students designated as ELLs but also supports the general student population in all learning spaces (Garcia & Figueiredo, 2012; Moschkovich, 1999b, 2005; Ramirez et al., 2003). Students experiencing this lack of support in instructional multimedia shows that design principles lack perspective and do not consider the needs of ELLs. A shift in design principles for instructional media towards inclusive practices for all student populations is necessary.

Research Question 4: Student Centered WEVs

The final question in this study seeks to understand how these purposefully designed WEVs impact student academic performance and if changes in design principles should become part of all instructional media design processes. Data collected via WEV math problems, interviews, and member-checking sessions, provide a rich data set from which to draw conclusions and create a rich narrative centering student experience when engaging with WEVs. Significant changes in academic performance emerged as students engaged with both experimental and control WEVs. However, students that engaged with experimental WEVs demonstrated higher academic achievement when completing problems embedded in WEVs. Interviews and member-checking sessions validate these findings. Students had the opportunity to see both WEVs during interviews and member-checking sessions and the consensus was that the experimental videos contained media elements that students found to be helpful in supporting their academic success. These elements are closed captioning, colorful text and images, familiar voice, graphical displays, and student selected music. When asked about these specific elements during interviews and member-checking sessions, students agreed that all of the elements were helpful to them and should be included in instructional media design principles. Below is a conversation specifically about the music which was chosen by one of the students.

> **RRR**: "can anyone share what they thought was helpful in their video?"
> **JJ**: "music was good"
> **JT**: "yeah, didn't PR pick the song?"
> **PR**: "yeah it was me, Mr. R asked me a few weeks ago"
> **RRR**: "why the music?"
> **JT**: "I just really like Bad Bunny and since I'm always listening to it, it put me in a good modd"
> **AJ**: "yeah it has a good beat and it wasn't super loud"
> **AA**: "yo but what if we could just pick from a bunch of songs that we all picked?"
> **PR**: "like a playlist we make and then we get to pick one"

Another conversation we talked at length about the closed captioning. Below is a portion of that conversation.

> **RRR**: "a lot of you mentioned the closed captions as being really good"
> **LD**: "Mr R, you cool but sometimes you talk to fast, so the captions helped when I couldn't understand"
> *group laughs*
> **RRR**: "ELL struggles, you know how that is (laughs) so they helped?"
> **PR**: "I didn't read them all the time but I glanced when I didn't understand a word or two"
> **AR**: "yeah same here, it was a good backup"
> **PA**: "my video didn't have them but I wish it did"
> **AJ**: "yeah my video didn't have em either, whack"

More conversations eventually led to a discussion about the narration, and they especially liked the fact that someone they knew was narrating the videos. As we see from the transcript above, they were thrilled that the music they had suggested found their way into the videos. They felt this was very important as they saw they had some agency in their own education process. Research shows that when students see themselves in the content they are learning (Moran, 2011; Scott, 2012), when they have some agency, they are more likely to engage and perform well in academic spaces.

This chapter provided a detailed description of the findings that emerged through collaborative data analysis. The first phase of data analysis yielded quantitative results showing that not only there was a positive correlation between student engagement with WEVs and academic performance, but also data which influenced the questions that were asked during individual interviews. Questions were chosen based on individual students' engagement with their assigned WEV as well as their academic performance. The second phase of analysis provided a rich data set of codes, from which the top 10 codes were utilized for discussion and further exploration for the rest of the research. These 10 codes are arithmetic, video, difficulty, knowledge, procedures, emotions, notes, slope formula, fractions, and prior knowledge. The third phase of analysis allowed students to co-analyze findings, as well as share their individual experiences with me and each other. These member-checking sessions provided a rich data set which allowed all of us to better understand their individual experiences and how WEVs can be designed to better support not just ELLs but the general student population as well. The last phase of analysis, included all data sets collected throughout the study, found that the experiences of students are valuable and must be considered when designing WEVs. Further research is needed to fully understand how to incorporate the student experience in the design of instructional/remediation multimedia.

CHAPTER 5

CONCLUSION AND IMPLICATIONS

In this multi-phase mixed-methods study, I sought to understand student engagement with Worked Example Videos (WEVs). Specifically, how, and why students designated as English Language Learners (ELLs) engage with this type of instructional/remedial multimedia. I wanted to understand if student performance changed after engaging with WEVs and the specific student experience, including what they found to be helpful and not helpful in each of the WEVs.

To understand student engagement and student experiences when engaging with instructional/remedial multimedia used in the classroom, this study sought to answer the following questions:

1. How and why are students engaging with worked-example videos?
2. How do students' Mathematics performance change before and after watching a Worked Example Video?
3. What are the specific experiences of ELLs as they watch worked-example videos as part of their mathematics learning process?
4. How effective are newly designed illustrated Worked Example Videos for ELL's and other student populations?

The multiple phases of this mixed-methods study allowed me to develop a profound understanding of student engagement with WEVs, and the specific nuances of the ELL experience. As each phase informed the next, the study was able to re-imagine itself and allow for flexibility in questions that were asked as well as discussions with students in member-checking sessions. In this next section I explain conclusions the students and I had throughout the study as well as final conclusions from the last phase of data analysis. By involving students in this knowledge making and understanding, this study centered the voices of students who are often ignored when developing strategies and curriculum in education. This choice is critical as we move away from extracting data from participants, and instead work towards understanding through community building and dialogue.

Conclusions

With the first research question, I sought to understand how and why students are engaging with WEVs. This question is crucial because understanding how and why students are engaging with WEVs can inform design principles to create more opportunities for purposeful interactions with videos. As students explained in interviews and member-checking sessions, their engagement with the videos were mostly pausing to write notes and rewinding to see the worked example again. These interactions tell us that students are not being passive participants, but instead taking agency and actively engaging in the learning process with note taking being one of their learning strategies. Although, many students shared that they usually just copy down anything the teacher writes on the board even if they do not understand what is being written, note taking can prove to be useful, as some students mentioned using them when calculating slope. Many students also hovered over areas of the video as it played. When asked about hovers, students shared they were focused on that specific idea shown on the video and the hover was a way to visually focus their attention as well. Further conversations during member-checking sessions led to understanding hovers as focused points of engagement in the physical space of the video. Through various conversations, we began to understand the importance of actively engaging with WEVs. During member-checking sessions and interviews, when presented with these findings, students concluded that they believe their interactions did in fact help them in calculating slope. The students and I concluded that videos that purposefully provide opportunities for students to interact or engage with the content, will likely lead to better academic achievement outcomes. Students also pushed me to see the video as another form of dialogue between student and educator and not just passive media students consume. Although the videos were not designed to specifically create points of engagement, students and I agreed that the data supports this conclusion.

The second question sought to see if students' academic achievement changed after watching their assigned WEV. Quantitative analysis showed a statistically significant difference in academic achievement between the control video group and the experimental video group as well as a strong positive predictability between student engagements and academic achievement. When discussing this analysis with students during interviews and member-checking sessions, students began to try and figure out the differences between the two videos. We concluded that some specific elements of the experimental WEV may have had some influence on the academic outcomes but did not make a direct cause and effect connection. As I stated in my findings section, students believe that the captions and the student selected music may have had some influence on student academic achievement. We discussed the idea of recreating their study/learning space during informal and formal assessments, to which almost all students responded positively since it is very common for them to listen to music when working independently or taking quizzes/tests. We concluded that while both videos proved to be useful in some capacity, students felt the specific differences in the experimental video made the learning space informal and more welcoming and thus connected to the increase in academic achievement. While the quantitative analysis shows statistically significant results, these findings alone do little to explain the student's academic experience. Member-checking sessions and interviews showed that the student experience supported the quantitative findings and students experienced positive feelings after watching videos. These feelings were more prevalent in the experimental group.

The third question looked to understand and amplify the student experience as they watched WEVs. Several conclusions were collaboratively drawn throughout this study as students and I grappled with their individual and collective experiences. We chose to focus on two crucial conclusions that would have the most implications. First, as mentioned previously, instructional/remedial multimedia design principles need to include the voices and experiences of students. As we discussed their individual experiences during interviews and member-checking sessions, the joy students exuded as they were allowed to share and voice their experiences and opinions, while not measured, was palpable and often talked about. A shared feeling, many were surprised they were included in this process since it is not common in learning spaces to ask students what they think or feel as they engage in learning. In 19 out of the 25 interviews, after I explained and each student understood the process of the research, each asked varying versions of "wait, you're actually going to listen to what I say?". I was always met with excitement and eagerness to participate as I said yes, and explained how valuable each individual experience is. This feeling of inclusion translated into increased engagement and commitment to learning. Something interesting that happened, and was unexpected, after member-checking sessions were over and I went back to data analysis, I noticed 8 different students had gone back and re-done the assignment and watched their assigned WEV again, answered all four slope calculation questions, and submitted another recorded video. These videos were not included in the data set, and I did not follow up with the students that submitted these second videos. However, it's important to point out that this extra participation was likely to due the fact that they knew they were being included in the teaching, learning, and research process and felt their experiences were valued.

A second conclusion we found was that students experienced a variety of feelings as they engaged with the videos and worked through the slope calculation problems and these feelings are not taken into account when designing instructional/remedial media for the classroom. Traditional approaches to learning and instruction do not consider the emotions students manage as they engage in learning (Greher, 2004; Pekrun, 2014; Yadav, 2018). Multimedia design principles, while not explicitly stated, do very little or completely ignore the emotions of students as they focus on concepts like procedural and conceptual knowledge (Mayer, 2003; Noetel et al., 2022; Vaughan, 1993). While these are important concepts to consider in learning and instruction, we found that students understood how important their emotions are and how impactful they can be on learning. This is backed by extensive research in education and math anxiety (Gillmor et al., 2015; Hutchinson, 2010; Yadav, 2018) which finds that negative emotions negatively impact student engagement and achievement. Inversely, positive emotions positively impact student engagement and achievement. As students explored the various emotions felt while watching videos, we learned that emotion management is an important skill to work on, but also something multimedia design principles should also work to support. Students shared that they want to feel good when engaging with educational content and often they feel dumb, inadequate, nervous, and scared. Through various conversations we concluded that multimedia design principles need to include aspects of emotion management.

The fourth question focused on the effectiveness of a WEV purposefully designed to address the needs of ELLs. Through quantitative analysis, we see that the experimental WEV had a statistically significant impact on student success in calculating slope. Although this quantitative result is important, it was crucial to also have discussions with students as to how they experienced each of the videos and if their experiences supported this finding. Quantitative data analysis is not enough to fully capture effectiveness of WEVs. Interviews and member-checking sessions led to some passionate discussions and as students from the control group shared their experiences with students from the experimental group and vice versa. Control group students said they would have benefited from closed captions as well as different narration in the video when these were brought up by the experimental video group. This finding coincides with other research in the field of effective educational videos by Cynthia J. Brame (2015) which "reviews literature relevant to each of these principles and suggests practical ways instructors can use these principles when using video as an educational tool." (p.1). In that paper, Brame explores principles of multimedia design that increases student engagement. Of those discussed in the paper, one is a conversational tone in narration, also called the personalization principle by Mayer (2008). Students explained how hearing my voice, a familiar voice to them, gave them a feeling of comfort and allowed them to commit to learning. The design elements implemented in the experimental group video, which students mentioned throughout interviews and member-checking sessions, are effective in helping them understand content and consequently in calculating slope. This final conclusion initially focusing on effectiveness of purposefully designed WEVs, naturally flowed into a conversation specific design elements in each of the videos, and eventually centers the student voice, which research has found to be beneficial in increasing engagement and learning (E. Lee & Hannafin, 2016; Wilson et al., 2018). While this study looked to explore the student experience when engaging with WEVs in the mathematics classroom, the importance of centering the student voice became a central point of discussion throughout the research. Once students learned that their opinions and ideas were valuable throughout this research, their eagerness to share showed through body language and willingness to share. This narrative has several implications for current pedagogy, design principle in multimedia, and future research.

Implications

Each of the co-constructed conclusions have implications for teacher pedagogy, multimedia design principles, and future research. As we look to re-imagine the high school classroom, we can look to inclusive research which centers the student experience to help us create an inclusive space in which all students can feel welcome and safe to learn.

The first conclusion pushes multimedia design principles to consider how students will be engaging with media designed for instruction and remediation. By understanding the reasons students are engaging with content, media designers can work with teachers and students to create purposeful points of engagement in which students are creating connections between previous knowledge and new concepts. Points of engagement can be included in media in which students are in dialogue with the teacher, and not just passively consuming educational content. Students shared that they liked having to answer questions after the video but shared that they would have also liked more questions between explanations and steps in the worked-example. We argue that future WEVs need to not only show a solution, but also engage the student throughout the process and check for understanding as the solution is shared.

The second conclusion affirms the use of WEVs as instructional and remediation tools in the classroom and expands to shed light on how students view these tools. This implies that teachers should make use of this tool in the classroom as well as outside the classroom to engage students in ways that formal lecturing may not. Once of the aspects students enjoyed was the ability to pause and rewind the video, something they cannot do in class. As we look to re-imagine the learning space, shifting control to the learner can be empowering. Teaching pedagogy should look for other ways to empower students to have more control when learning.

The third and fourth conclusions centered the student experience and push us to include those experiences as we create inclusive learning spaces and effective multimedia for instruction and remediation. These documented student experiences allow us to re-imagine a space in which student voice is central in decision making and strategies used in the classroom. Considering the emotional impact on students as they engage with instructional multimedia requires teachers to view students as whole humans, full of experiences and knowledge. Mathematics is known to cause students high levels of anxiety and discomfort. Multimedia design strategies that look to eliminate negative emotions, or at the very least give students tools to successfully manage their emotions as they engage with content, should be included in future research.

The last conclusion concerning design elements specifically employed in the experimental video, helps us re-conceptualize the design process. While extensive research has produced successful multimedia design principles (Berney & Bétrancourt, 2016; Mayer, 2003; Moreno & Mayer, 2000; Noetel et al., 2022; Vaughan, 1993), the student experience is not centered and often completely ignored in the process, many of which solely rely on quantitative data analysis. I argue that quantitative analysis can be helpful, however it does not go far enough in capturing the experience of the learner and thus is incomplete.

Lastly, pedagogy in the classroom could benefit from a student-centered approach as has been found in other literature (E. Lee & Hannafin, 2016; Sharrock & Rubenstein, 2019; Wilson et al., 2018). Allowing students to listen to music has become a normal routine in my classroom, something students shared helps them focus and found helpful in the WEVs.

Limitations

The research project also had some limitations. Limitations are weaknesses found through the research process that were out of my control (Creswell, 2012). Due to the Covid-19 pandemic, all interviews and member-checking sessions had to be conducted virtually, which limited the types of interactions. In a physical in person space, body language, gestures, and mannerisms can all be included as data. However, due to data collection being conducted over zoom, this limited contextual understanding that could have been achieved in person. The limited interactions prevented students from receiving in-person support from me as well as support from their peers. Another limitation was the inability to collect student work as they worked through the problems in the videos. Initial design of the research, students would submit their papers with any work since it would have been in person. The absence of this data set forced students to recreate what they were doing and thinking while watching videos.

One other limitation was the type of videos produced for the research. Initially, videos designed for the experimental group were created as animations. However, upon researching popular educational videos used by educators and students, like those found on Khan Academy, I had to instead create similar videos to those found with some slight changes in design principles. Although the changes proved to be beneficial for students, videos were very similar and did not allow for full creative expression. Future research may benefit from less limitations on experimental videos.

Future Research

Future research that can build upon this body of knowledge would include students as video designers as well as researchers. We see throughout this study that students are creative and have great ideas as far as what can be helpful in multimedia design. A study in which students design videos with peers could provide a rich data set from which principles for multimedia design can be understood and shared. By providing students with the tools and resources to own their learning processes, we can empower them as leaders as they enact change in education.

Final Thoughts

This research explored the lived experiences of students as they watched and engaged with WEVs. Students and I had fruitful conversations in which they shared their experiences candidly with me and each other. Many times, I was questioned as to why I wanted to know so much and if any of this mattered. I reassured students that I valued their opinion, and my goal was to help others re-imagine what these videos could look like if they centered the student experiences and not just numbers from questions answered correctly. The inclusion of students in the research process should have started from the beginning of the research. I designed the videos for the experimental group based on literature on multimedia design, much of it based solely on quantitative data. This mixed-methods study allowed me to have conversations, alongside quantitative data analysis with students, which created a rich data set from which to create a more complete and comprehensive student experience. As a member of their community, students valued the work we were doing and invested into the project. As I finish writing this dissertation, I look forward to re-connecting with some of those students and sharing my thoughts, hoping they will also share their thoughts with me. I continue to keep in touch with some of the participants and we speak of their futures, some plan on going college, one is joining the military, another is joining a family taqueria, and others have zero plans. I was able to share with them the progress on the research and many were happy to hear it was almost finished. They were particularly proud of the quotes I chose, and very happy to see that I did not change their words, “no cap Mr. R, that’s ill”.

As I write this last paragraph for my dissertation, I’m left with a sense of discomfort in that I was not able to give these students that invested so much into my work, and my research, anything tangible in return. They earned good grades on these assignments, got some food while we did the zoom sessions, but outside of that, they are seeing no other benefits while I can complete a Doctorate in Philosophy. Something that will have a tangible impact on my life and my future. I hope in future research I can fully compensate participants and their community. Extracting data is not the way I wish to participate as an academic and educator. As I left a graduation a few weeks ago, I felt happy for that student, her family, her community and proud of what they achieved. It took a village and I hope future research I engage with also takes a village.

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APPENDIX A

CALCULATING SLOPE RUBRIC

Score	**Description**
4.0 Exceeds	Students can correctly complete a complex calculation of slope given a table of values, two (x,y) values, or a graph.
3.5	
3.0 Secure	Students can complete a calculation of slope, with 1 or 2 errors, given a table of values, two (x,y) values, or a graph.
2.5	
2.0 Developing	Student can set up the calculation of slope given a table of values, two (x,y) values, or a graph.
1.5	
1.0 Beginning	Students can identify necessary values needed for the calculation of slope given a table of values, two (x,y) values, or a graph.
0.5	
0.0	Student did not attempt to solve the problem.

APPENDIX B

VIDEO URLS

Video URL	Audio Media Principles	Visual Media Principles
https://youtu.be/R948Tsyq4vA	Math work narrated live	Graph of a line, written text as it is narrated, uses different colors
https://youtu.be/WkspBxrzuZo	Math work narrated live	No images, text written as it is narrated, uses different colors
https://youtu.be/pGsicLglzY8	Math work narrated live	No images, text written as it is narrated, uses different colors
https://youtu.be/O8fo4H_185g	Math work narrated live	Graph with points, text written as narrated
https://youtu.be/S_uKdphJrZo	Math work narrated live	No images, text written as it is narrated, uses different colors

APPENDIX C

INTERVIEW AND MEMBER CHECKING PROTOCOL

Individual Interview Protocol

Opening Remarks: (after greetings)

Today we're going to spend some time talking about the video you watched, the four slope calculations, and your overall experience. Before we begin, I hope you know that your experience is very important to me and others and I want you to be as honest as you feel comfortable. We can stop at any time that you wish, and you won't be penalized at all. I'll be taking notes and also recording our conversation. Any questions before we get started?

Student Background

So I want to know a little about you as a student, how would you describe yourself as a student and tell me a time that you felt successful as a student in the math classroom.

1. How are you? How do you feel today?

2. What language/languages do you speak at home?

3. Do you like math? Have you always liked/disliked math?

4. What has your experience with math been like?

5. Tell me about a time where you felt successful in math.

6. Describe a typical day for you in the mathematics classroom.

General Video Questions

So now we are going to talk about the video that you submitted in which you watched a worked-example and attempted to calculate some slope problems.

1. What has been your experience with these types of videos?

2. Why did you pause/rewind the video at this point?

3. What were you thinking at this point when you paused/rewound the video?

4. What were you thinking at this point when you were writing?

5. What difficulties did you face while watching the video? (or a specific part of the video)

6. What did you find (most) helpful in the video?

7. What did you find least helpful in the video?

8. How did you feel watching the video?

9. What was your favorite part of the video?

10. What would you like to see? What would make you want to watch this video? What would make this video more interesting?

Member-Checking Sessions

Ok so today we're going to have a conversation about your experience with the videos you watched some weeks ago for class. I sent you all links to your individual video and you each said you watched them in preparation for our zoom session today. You all also have the transcript of your individual interview with me which I'll be referencing from time to time.

1. Did anyone struggle with the first slope calculation problem? Second problem? Third problem? Fourth problem?

2. What did you find helpful from the video in calculating slope?

3. Did anyone take notes? Why did you take notes? Did you use the notes?

4. Was anyone distracted while watching the video? Let's talk about it.

5. Specific transcript questions as they relate to other students.

APPENDIX D

IRB APPROVAL DOCUMENT

ASU Knowledge Enterprise Development

APPROVAL: EXPEDITED REVIEW

Mi Yeon Lee
Division of Teacher Preparation - Tempe
480/727-9376
Miyeon.Lee@asu.edu

Dear Mi Yeon Lee:

On 2/19/2019 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Illustrated Worked Example Videos: An Intervention Supporting Students Designated as English Language Learners
Investigator:	Mi Yeon Lee
IRB ID:	STUDY00009594
Category of review:	(6) Voice, video, digital, or image recordings, (7)(b) Social science methods, (7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Consent Spanish, Category: Consent Form; • Cognitive Load Math Problem Protocol, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol, Category: IRB Protocol; • Consent English, Category: Consent Form; • Cognitive Load Protocol, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Recruitment English, Category: Recruitment Materials; • Assent English, Category: Consent Form; • Recruitment Flyer English, Category: Recruitment Materials; • SDUSD Research Approval, Category: Off-site authorizations (school permission, other IRB approvals, Tribal permission etc); • Recruitment Spanish, Category: Recruitment Materials; • Linear Equation Math Problems, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Video Recall Interview Protocol, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Translation Certification Document, Category: Translations; • Assent Spanish, Category: Consent Form;

The IRB approved the protocol from 2/19/2019 to 2/18/2020 inclusive. Three weeks before 2/18/2020 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 2/18/2020 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the “Documents” tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Rolando Robles
Rolando Robles