University of Portland
Pilot Scholars

Graduate Theses and Dissertations

2018

The Effects of Digital Game-Based Learning on Algebraic Procedural and Conceptual Understanding and Motivation Towards Mathematics

Heidi Meister

Follow this and additional works at: https://pilotscholars.up.edu/etd

Part of the Curriculum and Instruction Commons, Educational Methods Commons, and the Science and Mathematics Education Commons

The Effects of Digital Game-Based Learning on Algebraic Procedural and Conceptual

Understanding and Motivation Towards Mathematics

by

Heidi Meister

A dissertation to be submitted in partial fulfillment
of the requirements for the degree of

Doctor of Education
in
Leading and Learning

University of Portland
School of Education

2018

The Effects of Digital Game-Based Learning on Algebraic Procedural and Conceptual Understanding and Motivation Towards Mathematics

by

Heidi Meister

This dissertation is completed as a partial requirement for the Doctor of Education (EdD) degree at the University of Portland in Portland, Oregon.

Approved:

Redacted

_____   _4/3/18_
'Chairperson   Date

Redacted

_____   _4/3/18_
Committee Member   Date

Redacted

_____   _4/3/18_
Committee Member   Date

If applicable:

_____   _____
Additional Committee Member   Date
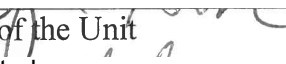
_____   _____
Additional Committee Member   Date

Approved:

Redacted

_____   _4-3-18_
Graduate Program Director   Date

Redacted

_____   _4/3/18_
Dean of the Unit   Date

Redacted

_____   _April 3, 2018_
Dean of the Graduate School   Date

Abstract

This study examined the impact of digital game-based learning (DGBL) on procedural and conceptual understanding of algebraic expressions and equations and the motivation of students towards classroom mathematics. The mixed-methods sequential explanatory design was used in this study to collect data to determine the effectiveness of DGBL in a 7th grade STEM class. Following a pre-test and pre-motivation survey, students were assigned to either the DGBL group or the non-gaming computer applications as supplemental to mathematics instruction. In order to address both procedural targets and conceptual targets students would be using the technology interventions in addition to traditional math instruction as part of their daily math class, and a problem-based unit taught as part of their STEM class. Following the treatment, a post-test, post-motivation survey, and a conceptual assessment were administered, as well as a digital questionnaire. No significant differences were detected between their understanding of procedural or conceptual problems, nor was there a significant impact to their motivation towards mathematics based on the quantitative data gathered. Students displayed an enthusiastic response to the DGBL environment based on their transcripts from the follow-up questionnaire. The results of the study imply that there is a need for further development of DGBL systems and scaffolded supports to assist students in making connections from the digital environment to classroom mathematics. It further indicates that enjoyment of the DGBL environment does not necessarily transfer to motivation to learn the subject matter in the non-digital environment.

Acknowledgements

I would like to express my gratitude to my chairperson Dr. Patricia Morrell for her constant support and guidance throughout this project. I always felt lucky to rely on her good judgement before taking any step regarding my research and I will consider her a role model throughout my career. I would also like to express my thanks to Dr. Nicole Ralston and Dr. Carolyn James for their guidance and professional expertise.

Many thanks to my Cohort 3 colleagues at the University of Portland who supported my professional journey during my time as an Ed.D. student for the past three years. I am honored to have had the privilege to work with this group of talented and caring individuals.

Needless to say, I am forever thankful to my dear friends, family and colleagues who encouraged and supported me along the way. Thank you Colleen Wigman for being so patient with your mom, and understanding all of the hours of sitting at a computer. Thank you Jessica John for being the most amazing and supportive partner that I could have ever asked for.

Table of Contents

List of Tables

List of Figures

Chapter One: Introduction

If we teach today's students as we taught yesterday's, we rob them of

tomorrow. (Dewey, 1944, p.167)

In the early 20th century, progressive educational reformer, John Dewey envisioned an education system of the future. In his work, *Schools of Tomorrow*, Dewey **(**1915) called for curriculum reform by looking toward the future needs of society in order to determine the direction classroom instruction and experiential learning should take. Dewey argued that reorganization of the education system should be based on placing emphasis on the individual and providing the freedom to access relevant and engaging learning (West, 2011). Regimens of innovative thinking and technology to solve the problems of low achievement and low engagement have been prescribed. More than a century after John Dewey's call for education reform, we are still grasping to determine the cause of the lack of knowledge transfer and limited motivation in the classroom. Looking at the system in entirety, the business model mentality that has provided the base for education is almost unchanged in the past 50 years (Canada, 2013).

Understanding the ways in which students acquire knowledge is vital in order to design systems that support learning. Learning is not just a process that happens within the confines of classrooms at an educational institution but, with the ease of access of information, can take place anywhere and at any time. The traditional method of learning in which students navigate their way through formal and informal contexts within a classroom and at the discretion and authority of an educator is limiting in the digital age. As the acquisition of knowledge is gained through multiple inputs, there is an increase in the ways in which learners can interact with the new information. The changing demographics of the student population has led to new ways of addressing the changing roles of the learner – and attempting to answer the question of how they

are making meaning of the world around them. As students are required to utilize technology for an increasing amount of tasks – from accessing digital textbooks, to creating interactive presentations, to gaming with their cohort; they must learn how to transfer the content from the digital platform to their physical learning environment. This study will examine the impact of technology on two issues present in learning environments today: utilizing game-based learning to develop conceptual and procedural understanding used in the classroom, and the attitudes towards mathematics.

To treat the students of today like those of decades ago is selling them short on their education. This generation has grown up with technology integrated into their daily lives, and they demonstrate incredible fluidity with and dependence on their devices (Chien, 2012). The key to the next step in education is to learn how to best utilize the knowledge base of our students and areas of engagement to lead them on their journey through education in the digital era. With each new decade, there has not only been an increase in technological advances, but also the ways in which we incorporate their various forms into our lives. Consumer technologies can be traced back to the mid 20th century with radios and televisions in the sixties; personal gaming systems, boom boxes, and VCRs in the seventies and eighties; compact discs, DVD players and the Internet in the nineties. The 21st century has brought with it smart phones, interactive virtual reality devices, and online global communities with populations larger than some countries. Technology has taken the front seat in our daily lives. In terms of access to technology for the global population, the pace from introduction to saturation is incredible: radio took 40 years to reach 50 million users and the internet reached the same in less than five years (Rosen, 2010). In a single year, YouTube went from inception to 50 million consumers (Rosen, 2010). A large majority of these consumers sit in K-12 classrooms around the world.

Technology has increasingly become part of the mainstream classroom environment throughout the nation [National Science Foundation (NSF), 2008], but has yet to make a major impact with regards to learning that can be empirically attributed to it. As far as an accessible tool that users are motivated to use and generally intuitively knowledgeable about, technology, in all of its various forms, is an excellent medium for delivering educational content. The success of a classroom in which technology supplements instruction and facilitates learning fits with the modern, high-tech, global world better than outdated practices of learning that are often present in classrooms today. This study will provide a lens to look at the potential for the technology to be applied in a manner that targets two variables of education that are tied to student success: (a) the ability to develop procedural and conceptual knowledge in mathematics, and (b) the level at which a student engages and is motivated to continue learning.

The State of Educational Technology

Despite the revolutions wrought by technology in medicine, engineering, communication, and many other fields, the classrooms, textbooks, and lectures of today are little different than those of our parents. Yet today's students use computers, mobile telephones, and other portable technical devices regularly for almost every other form of communication except learning. (NSF, 2008, p.12)

Generation X, *Net-Geners*, the *iGeneration*, and *Genration.com* are all terms that have been used to refer to the wave of learners that have redefined communication in the digital age (Rosen, 2010). Social media has become the center of their identity with Snapchats, profiles, friends, followers, likes, tweets, IMs, and selfies representing new forms with which to share information with one another and to be exposed to new information about the world around them. In addition to communicating with one another, a majority of users has created their own

content in the form of YouTube videos, games, profiles, photography, music, and 3D printed materials. Interestingly enough, these are many of the same types of products that our education system has demanded for generations, but required in a format that is unfamiliar and unengaging to many of our students. Fittingly put by James Paul Gee, theoretical linguist and esteemed educational researcher, "given that the digital age is enveloping our world, and its influence is not likely to decrease, educators need to meet the emerging challenges on two fronts. Educators must determine the new learning styles of students and develop educational methodology and teaching strategies to meet learning needs" (as cited in Rosen, 2010, p. 3).

Learners of today have grown up on a diet of multi-media; students' learning has increasingly been made external to the classroom and takes place over various forms of technologies. What it means to be a learner in the digital age goes beyond basic competencies and dives deeper into applying knowledge to new situations, analyzing information, communicating, collaborating, and problem solving. Over the last three decades there has been an increasing urgency for educational reform, with states, districts, and schools having gone through a multitude of design and redesign measures. Educational technology policy and collaborative efforts have confronted the challenges of the digital age by addressing topics such as improving infrastructure, providing professional development for educators, increasing funding, establishing partnerships with the private sector, updating technology regulations for school use, increasing research on educational technologies, and creating high-quality content and software (Culp, Honey, & Mandinach, 2005). Unbelievable progress has been made on the entertainment side of technological development, but little progress has been made in the way on the educational access and learning-software side (Gee, 2007; Rosen, 2010).

The idea of using technology in education is not new. Many classrooms are outfitted with projection devices that communicate with a digital suite of applications, animations, movies, audio tracks, presentations, and more. Oftentimes schools provide their students with laptop carts that can be wheeled from room to room, computer labs, or even one-to-one programs that can carry acronyms like BYOD (Bring Your Own Device), or individual units provided by the districts themselves. According to a report on education technology spending in the United States, K-12 spending on classroom technology in 2015 was expected to reach $4.7 billion dollars, with $522 million spent on tablet type devices alone (Schaffhauser, 2015). The monies allotted to the development of adequate infrastructure, upgrades to current systems to withstand the increased bandwidth, and software marketed for educational purposes are barely justified when schools are still reporting underperforming achievement statistics. Budgetary requests address the substantial amount of funding necessary to implement and maintain programs, whether a dedicated lab, classroom cart, or one-to-one program, and can fall on deaf ears when the technology is misused or seemingly ineffective by standardized assessment measures. Proposed explanations can range from the lack of accountability and equity with educational technology policies, the lack of software targeting intermediate and advanced subjects, to an absence of an established mechanism for transferring knowledge from the digital space to the classroom (Culp, et al., 2005; De Smedt, Ansari, Grabner, Hannula, Schneider, & Verschaffel, 2010).

Google for Education has been at the forefront of much of the technology that is currently making a major impact in schools (Dessoff, 2010). In an attempt to provide a massive overhaul to a struggling education system, in 2010 Oregon became the first state to sign an agreement with Google to offer its suite of Apps for Education to all of their public schools (Dessoff, 2010).

The Oregon Department of Education and Google partnership provides a variety of interactive, collaborative, and engaging tools that target learner-centered design and are becoming more popular within classrooms (Dessoff, 2014; Downes & Bishop, 2012). In 2012, Google introduced their version of a laptop, attractive to the limited funds of schools at a price point under $300 (Herold, 2014). These inexpensive, web-based laptops accounted for one-third of all devices sold to schools in the United States in 2012 (Dessoff, 2014). This go-to learning device is a high-priority purchase for 49% of districts across the nation, and from 2014 to 2015 saw a 17% increase in acquisition (Schaffhauser, 2015). An increasing number of software developers are creating avenues to ease the burden of a lengthy sign up and have allowed login using student google accounts. Google's Chromestore offers learning apps that address a variety of educational needs from flash cards in multiple subjects, keyboarding tutorials, organization of calendars, and foreign languages. Google is just one of many providers that is answering the call of educational reform based on a changing society and addressing the needs of a radically different generation that sits in the classrooms today. As devices have made their way into classrooms, there is an increased need for the guidance in the transfer of knowledge from digital to classroom application and the development of highly engaging and relevant content with which to provide students so that the time spent accessing technology enhanced learning environments is not misdirected.

Game-Based Learning

Games have been used as educational tools for generations; Plato's use of philosophical discourse and the notion of hypothetical questions as a way of examining a different philosophical viewpoint can be thought of as mental play (Michael & Chen, 2006). Games like Peek-A-Boo, Hide and Seek, Simon Says, and others are played long before we enter the formal

classroom and teach concepts of socialization and organized learning. Military strategists have used games to teach military tactics for over a thousand years with games like Chaturanga, Chess, Wei Qi, Xiang Qi, and Baduk (Michael & Chen, 2006). In the 21st century, these games have taken a digital turn, and there is no doubt that they are a huge part of our culture.

Videogames and the immensely popular culture of the gaming industry comprise one of the largest influences on Americans (Squire, 2002). They are as embedded in the lives of adolescents as are social media, books, movies, television, and music. Data from a recent study from the Pew Research Center (2015) gave a good idea of the use of video game access and play among teens in the United States. According to the study, 72% of teens play video games on a variety of devices, 81% of 13-17 year-old students own a console specifically for the purposes of gaming, and 51% of this population use the game environment as a social tool during game play. Multimedia technologies and video games are a popular choice for youth and can serve as a readily available medium in which to deliver content. As game developers work with market demand, changing demographics, and latest hardware releases the issue is not as much dependent on whether the user has a tablet, phone, Chromebook, or desktop. There is currently access to an increasing variety of game types and genres, and with a quick glance through online app stores or streaming game rental and purchase sites it is easy to identify the top sellers.

Technology enhanced learning is used as an umbrella term for the vast amount of technologies that are utilized in education: projection systems, interactive whiteboards, digital response devices, laptops, software, etc. One facet of technology enhanced learning is Digital Game-Based Learning (DGBL), which refers to interactive learning environments that entice the learner with motivating and challenging problem solving (Gee, 2007). The reputation that DGBL is making for itself is becoming more widespread among education reformers as a

potentially engaging and motivating supplement to classroom instruction. Used in primary, secondary, and higher education, DGBL is delivered in multiple platforms (tablet, desktop, laptop), different genres (virtual reality, puzzle, strategy, action, simulation, etc.), and for a variety of purposes (entertainment, math, history, languages, health, etc.). Unfortunately, an all-too-familiar recipe for implementing DGBL is that students are provided a device, directed towards an "educational" app, then instructed to follow steps independently, with the assumption that learning is taking place. This is demonstrated through the bulk of the research on educational technology software development in the design of games that focus on recall of facts rather than perceptual and cognitive skills (Hainey, Connolly, Boyle, Wilson, & Razak, 2016). Some of the highest grossing games, marketed under the label of education are based on repetitive activities in which learners are motivated through extrinsic rewards of leaderboards and avatar animation, without much in the form of interactive problem solving (Hainey et al., 2016). The intent of this research study is to address how DGBL can be applied effectively to target specific skills, provide supplementary support in the classroom environment, and be used as a tool to motivate students to engage in the learning process.

With teachers taking on the roles of technology coordinators and pseudo-Information Technology (IT) professionals, there is limited knowledge as to which devices and software can target the higher-order thinking necessary for students to make relevant use of technology in the classrooms for anything other than entertainment. A name has been given to the type of software that has flooded schools in the form of applications, games, and interactives: *edutainment* (Hainey et al., 2016; Michael & Chen, 2006). The goal of games built around an edutainment design was to educate through entertainment. These games primarily focus on a young demographic, and are limited to teaching facts in math, reading, and science (Michael & Chen,

2006). Combined with advances in computer hardware, innovations in the graphic design software, and further research in the DGBL field, software that educates a larger audience in more advanced subjects through an engaging platform can be developed.

Delivering instruction that competes with the media-rich and interactive experiences that a typical student is exposed to is an enormous challenge for the teachers of today. Research in the field of educational technologies has encouraged new, interactive ways of delivering mathematics content by harnessing the power of video games to engage and teach. Good video games that are marketed to all ages and ability levels are increasingly complex and require the player to invest time into learning the mechanics of game play and background story. Fans of popular titles can even be found spending time outside of the game to learn strategies and "cheats" in order to master the game. Gee (2007) has suggested that the same principles of learning found in these popular games are on par with theories of learning found in the typical classroom and warrant attention within the realm of education.

Educational ideologies and pedagogical practices that addressed the needs of generations past continue to be used to answer the question of how children acquire knowledge and what constitutes learning (Gee, 2007). Concerns are paramount in discussions involving educators and researchers about the possibility of 21st century students needing a different approach when it comes to teaching; and those of us in the classrooms can attest that many of these children are in need and of want of a change in how content is delivered and how it can be accessed. One of the primary drivers behind an influx of technology into education has to do with the attitudes and enthusiasm of students in the digital age of the 21st century. The term "digital native" refers to an individual who shows an apparent ease of understanding, reliance, and natural familiarity on information and communication technologies (Bennett, Maton, & Kervin, 2008). Immersion in

all things digital is inherent with this demographic, and it is part of the culture of the students in today's classrooms. Current technologies have been increasingly brought into classrooms in an attempt to motivate, teach, engage, and broaden the student's access to learning.

Academic Motivation

Oftentimes, educators are faced with the task of trying to access the interests and goals of each individual student so that learning can be made relevant and engaging. Common questions arise regarding the relevancy of the algebra lesson in the life of a 13 year-old student, with empty promises of using the formula sometime in the future, and emphasizing its importance. The consensus among many in the field of academia is that if learners are not motivated, their academic achievement will be in jeopardy (Ames & Archer, 1988; Krapp, 1999; Mitchell, 1993). Lack of effort can arise from sheer boredom, work that is too demanding, or interest that lies elsewhere. With this lack of motivation can come neglect of studies and the deterioration of enjoyment in academic related activities. The concept of interest plays a predominant role in motivational factors in learning and development (Hidi & Harackiewicz, 2000; Krapp, 1999; Mitchell, 1993). According to researchers, the factors that are focused on intrinsic values of understanding work, improvement of competence, and an internal sense of self-empowerment are more apt to have continued success (Ames, 1992). What much of the research has demonstrated is that motivation needs to begin with an interest, and there needs to be a switch from a temporary state to a continual state of interest (Hidi & Harackiewicz, 2000; Mitchell, 1993). District-wide technology implementation programs have been partially driven by the notion that games can enrich learning motivation and heighten educational interests of students (Hwang, Wu, & Chen, 2012). Educational research from the past decade supports the notion and

has maintained a common theme: education can be enhanced with the use of interactive, engaging, and deliberately designed video games (Shaffer, Squire, Halverson, & Gee, 2005).

Procedural & Conceptual Knowledge

In the past decade, there has been steadily increasing pressure to ensure that high school graduates not only complete algebra but provide proof that they have developed a deeper understanding of problem-solving (Friedlander & Arcavi, 2012). From the years 2003 to 2011, the percentage of 8th graders enrolled in Algebra 1 courses has risen from 32% to 59% (Liang, Heckman, & Abedi, 2012). Looking at the numbers, one might conclude that more students are algebra-ready than in the past, yet teachers complain that the majority of their students are not ready for the material and can barely comprehend the algorithms, much less apply existing knowledge to a new problem (Friedlander & Arcavi, 2012). Standardized assessment items attempt to measure procedural and conceptual knowledge with multiple choice questions that have students complete various tasks with an emphasis on solving for the unknown variables of a problem. The cognitive demands are not only increasing as high-stakes testing continues to take center-stage, but the grade-levels at which competence and mastery are expected is at odds with the cognitive development of school-age children (Liang et al, 2012). While much of the mathematics prior to an Algebra course can be challenging, it is at this level in which abstract reasoning and reliance on the ability to apply formulaic knowledge to problems become important for the successful learning process (Friedlander & Arcavi, 2012).

In his 2010 TED Talk, high school math teacher Dr. Dan Meyer explained the state of a mathematics classroom, specifically algebra class, with humorous accuracy. Dr. Meyer broke down the teaching practices of mathematics into five points that most teachers would agree with: students have a lack of initiative, lack of perseverance, lack of retention, an aversion to word

problems, and the eagerness for a formula (Meyer, 2010). Dr. Meyer demonstrated by use of textbook samples and test questions how layers were added to content so that problem solving skills are no longer necessary in order to solve the problem; there is an illusion of higher-order thought, but it is delivered to the student in the most efficient way possible (Meyer, 2010). In too many classrooms today, the patient problem-solving and the development of mathematic reasoning have been replaced with a surplus of information and an over-simplification (in the form of aids, hints, and colorful cartoons and visuals) of complex problems.

Digital Game-Based Learning (DGBL)

One of the key challenges to DGBL is attributing successes in the classroom to the digital interventions used to supplement regular instruction. The process of transferring knowledge from a digital to a non-digital context is much more difficult than entertaining with simplified, repetitive practice style problems mashed with arcade-style games. Constructivist approaches to help students become more mathematically literate by way of procedural and conceptual knowledge, especially in the Algebra classrooms, by use of DGBL is a need in the research field.

One explanation of learning states that it is "any process that in living organisms leads to permanent capacity of change and which is not solely due to biological maturation or ageing" (Illeris, 2009, p.3). Another definition that is widely used is that learning is "the active construction of an individual's own knowledge by integrating new information with previous experience" (Shin, Sutherland, Norris, & Soloway, 2012, p. 541). A common assumption with learning is that if an individual has retained information then it is learned. Much of the educational software on the market has capitalized on this assumption. In terms of DGBL, the current measure of learning is often based on levels and outcomes that can be whittled down to simple multiple choice items or electronic worksheets with repeated practice sets.

The intent of DGBL is as a supplement to teaching that can provide a high-interest platform with which to deliver content. If technological devices serve the purpose of delivering poorly designed or meaningless content, then the engagement and outcomes that are expected will be at odds. A room full of primary students practicing math facts on a device using repeated patterns are following a method of habituated learning in which the expectation is that by applying a model-imitate-practice routine, students will transfer the content into learning. The paired responses, in the form of a repeated behavior coupled with a built-in reward system, is the basis of associated learning theories and are beneficial for the development of skills rather than formation of concepts (Anderson, 2010). As students are passively observing mathematics as a set of routines, patterns, and procedures in a non-contextual environment, there is continual struggle to use the concepts proactively and engage in a relevant way. The use of DGBL allows continuous learning engagement that can be expanded beyond basic competencies by applying knowledge to new situations, analyzing information, communicating, collaborating, and problem solving (Salpeter, 2003). It is time to make use of the strengths of the students in our classrooms and support the construction of meaning using the neurobiological system that they possess with a delivery method that is appropriate and effective. Deliberate design of DGBL not only incorporates a variety of learning principles but encourages the type of metacognition required to make explicit connections between patterns and concepts.

Educational video games that go beyond the format of drill and practice engage the student and create a multitude of opportunities for the player to learn through experiencing the content in a variety of contexts. Not only do games have the potential to target specific interests of students, they could provide a means of self-monitoring and evaluation that fosters the motivation of continued learning.

Purpose of the Study

This dissertation is intended to make a contribution to the field of education by identifying the transfer of learning that takes place from the video game to procedural and conceptual mathematical tasks and by analyzing the situational interest that leads towards motivation to continue learning in the mathematics classroom. The purpose of this mixed methods study is to investigate the effects of DGBL on problem solving skills and motivation of seventh grade math students. Specifically, the study will examine the impact of Dragonbox Algebra 12+ and answer the following research questions:

a) How does digital game-based learning impact procedural and conceptual mathematical understanding among students?

b) How does digital game-based learning affect learners' motivation towards classroom mathematics?

Preview

Chapter 2 will provide a comprehensive review of the literature around DGBL, procedural and conceptual knowledge, and motivation. There will be an introduction to a constructivist framework to support the development of learning through problem solving, Structure Mapping Theory to support the transfer of learning from the digital context to the non-digital, and research on the structure of motivation. Chapter 3 will provide the methodology that has been used in this study, and will describe the selection of the specific video game used for intervention, the methods through which the research was carried out, and information about the setting and the participants. Chapter 4 will present the research findings and data analysis. Chapter 5 will include a summary and discussion of the findings, limitations of the research study, and recommendations for future study.

Chapter Two: Review of the Literature

The main bodies of literature reviewed in this paper will provide a background for the importance of the role of Digital Game-Based Learning (DGBL) in the classroom. The literature review will start with examining the differences in the generation of students today and addressing needs specific to them. A proposed explanation of the method by which individuals acquire knowledge will be put forth through Vygotsky's Constructivist Theory, while also comparing the role of procedural and conceptual knowledge in mathematics education. The history of gaming in education, and the ability to transfer the learning from video game elements into the classroom will be addressed by transfer theories and research in scaffolding (Belland, Kim, & Hannafin, 2013; Gentner, 1983; Nokes, 2004). The examination of DGBL through a neuroeducation perspective will take into account the role of mathematical literacy to determine if there is an impact on procedural and conceptual understanding in terms of mathematics, and use research in the field of neuroscience and cognitive development as a rationale for the potential educational and technological revolution of DGBL. The components of motivation will be discussed by looking at the concept of situational interest (Mitchell, 1993) and how this may be targeted through DGBL. Empirical studies of the impact of DGBL on motivation will be presented to provide additional justification for the need for further research.

Constructivist Teaching Approaches

Understanding the ways in which students learn lies at the foundation of educational design and contributes to the importance of the role of DGBL. The constructivist view of learning has been influential in helping to explain the acquisition of mathematical knowledge and problem solving skills (Voskoglou, 2012). Vygotsky's (1980) Constructivist Theory states that as an individual experiences the world around them, they are actively constructing their own

knowledge by using past experiences to solve new problems. The constructivist approach is based on two main principles about how knowledge is constructed by the learner: it is actively attained and is in a constant state of change based on one's environment. In this type of active learning, the use of physical actions promotes the use of senses to obtain underlying meaning (Vygotsky, 1980). The main characteristics in this type of environment are hands-on and self-directed tasks that promote design and discovery (Illeris, 2009).

Constructivist approaches go beyond basic fact recall and play a role in developing an understanding that is at the deeper conceptual level and fostering the ability to communicate learned ideas (Ross & Wilson, 2012). The type of mathematical independent thinking that is created in a cognitive constructivist environment can increase a student's understanding, by applying prior knowledge to invented algorithms, asking questions, posing problems, and creating procedures for problem solving (Ross & Wilson, 2012). In relation to DGBL, the constructivist approach allows the player to construct their learning in a digital environment and then transfer this learning in a non-digitized context to problems in the real-world.

If constructivism is based on the learning from experiencing the world around us, then to address how meaning is derived from our environment would be a key element to explore. The term *semiotics* is used to describe representations that take on meaning (Gee, 2007). The symbols and signs around us stand for different meanings in different situations, contexts, practices, cultures, and historical periods (Gee, 2007). A *semiotic domain* refers to an area in which people think or act in certain ways communicated through multiple modalities (oral or written language, images, equations, symbols, sounds gestures, graphs, artifacts, etc.) that all take on distinct meanings (Gee, 2007). Actively learning a new semiotic domain can enhance the learning that takes place in a classroom by addressing fundamental characteristics of

education (Gee, 2007; Roschelle, Pea, Hoadley, GordinDouglas, & Means, 2000). Improvement of how and what students learn can be based upon the tenets of active engagement, group participation, frequent interaction and feedback, and connections to real-world contexts. With this approach, not only is the student acquiring content, but they are experiencing the world in new ways, building networks, increasing motivation, and preparing for future learning by building a solid foundation (Gee, 2007; Hidi & Harackiewicz, 2000; Vygotsky, 1980). It can be argued that "active learning" is not "critical learning" until the individual can understand and construct meaning in a unique semiotic domain and innovate and create in unpredictable contexts (Gee, 2007). For example, when engaged in a game, players often need to understand the patterns, language, and combination of elements that are designed into the programming, and react to new situations based on this understanding of what is allowed. As the players repeat their attempts at completing a task in the game play, based on acquired knowledge, they continually must readjust their methods in the face of new challenges, providing opportunities to reflect on their learning, and practicing metacognitive skills. Video games are an excellent demonstration of the kind of environment that learners can engage in, take risks in, make mistakes in, and develop new ways of problem-solving in, all the while avoiding the type of consequences that may deter them in the real-world (Gee, 2007). The specific evidence that will be presented in this literature review will make connections between the use of DGBL in a digital environment, the meaning derived from multiple representative structures during game play, and the transfer to measurable cognitive, academic, and motivational results.

Game-Based Learning in the 21st Century

A natural marriage of games and exciting new technologies sparked the video game revolution in the early 1980's, with consumer versions of popular arcade games. As these games

have "grown-up" from the simple joysticks to entire virtual worlds complete with goggles and physical manipulatives, they have found a place in education. The focus has shifted from a negative concern about the idea of using video games for learning, to figuring out how to use video games for learning (Sanford, Starr, Merkel, & Bonsor Kurki, 2015). The use of a computer games-based approach to deliver, support, and enhance teaching, learning, assessment, and evaluation is essential to the constructivist classrooms of today (Panoutsopoulos & Sampson, 2012). Well-designed video games have the potential to provide learning experiences that are developed by bridging abstract concepts with real-world applications.

Educational researchers have stated the importance of children's games in facilitating accommodation, assimilation, satisfaction, self-regulation, and complex understandings among many of the benefits (Mondéjar, Hervás, Johnson, Gutierrez, & Latorre, 2016; Weppel, Bishop, & Munoz-Avila, 2012). Piaget (1967) promoted play as a tool to expedite necessary processes that learners experience to make sense and relevancy of new information. Vygotsky (1980) noticed that when children were interacting with others during game play in their zone of proximal development, they were able to comprehend and grasp complex content in a deeper manner. The nature of games can contribute to cognitive processes and personal-emotional development of children and can easily be incorporated into video games (Mondéjar et al., 2016). Work by Cameron & Dwyer (2005), Malone (1980), Papert (1980), Rieber (1996) has paved the way for developers and practitioners to come together to create effective and engaging educational game design.

In a retrospective of education technology policy over the last 30 years, it has become clear that technology enhanced learning has been an increasing part of the classroom culture. The International Society for Technology in Education (ITSE) has developed a framework for

students, educators, and administrators to rethink education and to create innovative learning

environments in this constantly evolving technological landscape. The standards developed for

innovating the education of students today include empowering learners in leveraging

technology to construct networks to customize their learning environment and building

knowledge by actively exploring real-world issues and problems, developing ideas, pursuing

answer and solutions (ITSE, 2018). With the robustness of technology applications, there is not

a set method with which to construct their learning, but only an unlimited landscape with which

to explore. One of the tools with which to transfer a student's learning from the technological

input to application in the real world context is through the use of gaming. A comprehensive

mapping of gaming onto American Association of School Librarian's (AASL) *Standards*

Framework for Learners will reveal that games can accomplish many of the skills such as (a)

Standard 1.1.2 "using prior and background knowledge as a context for new learning," (b)

Standard 1.1.9 "collaborate with others to broaden and deepen understanding," (c) Standard 1.3.4

"contribute ideas within a learning community," (d) Standard 1.4.1 "monitor own information-

seeking processes," or (e) Standard 2.1.3 "use information gained to apply to real-world

situations" are addressed (2018). The educational potential of gaming has been well

documented, and with proper design can provide elements necessary to promote rich content

understanding among students (Barab, Gresalfi, & Ingram-Goble, 2010). Games that can

incorporate multimedia technologies and maintain principles of learning have the potential to

impact higher order skills that carryover into real-world situations (Nachimuthu & Vijayakumari,

2011).

There is a considerable amount of research that supports the view that educational

software and computer gaming have a huge role to play in the potential to impact pedagogy. Gee

(2007) outlined several reasons that video games should be used to teach. At its core, a game is basically a set of rule-based and artificial activities that have goals, constraints, payoffs, and consequences; much like the design of a classroom structure. By utilizing this familiar design, video games have the potential to build strong identities with new domains and role play in which a player can take on a distinctive character. Through the eyes of the character, the player can move through the virtual world using the very scientific process that is taught in the context of a textbook: hypothesize, explore the environment, get a reaction, reflect on the results, and redesign to get better results. In many video games, part of the redesign process allows for production of content, in the form of alterations, deletions, and insertions. The player can engage with the new content, take risks, explore, and try new things, all with a low consequence for failure. All of these elements are what problem solving demands, yet seems disconnected from classroom learning and student engagement. Educational games look to provide an engaging environment where users can customize game play to their level and style of learning, and develop a sense of agency, ownership, and control over their education (Gee, 2007).

The term *video game* can bring to mind the image of students engaged in meaningless play. Commonly held attitudes about learning is that it is something that takes place in school and is related to solely academic disciplines, so the idea that instruction could look like a game can be hard to swallow. In reality though, when people learn through the use of video games that combine words, symbols, and representations with images, they are learning a new form of literacy (Gee, 2007). If literacy is viewed as more than just words on a page, then the ways in which literacy skills can be developed and learned should be expanded to virtual environments complete with representations that require interpretation. When approaching literacy in terms of semiotics, the implication is that basic signs take on meaning; they are more than just stand alone

pieces of a puzzle. Depending on the context in which these signs are used also impacts the

meaning-making. Considering that the modern, high-tech, networked global landscape is a new

type of semiotic domain, a need is established to become literate in new ways, utilizing different

methods.

The types of games that have invaded classrooms have overwhelmingly been comprised

of simple drills that can be mastered relatively quickly and require very little decision-making or

strategy (Hommel, 2010). As research in the field of DGBL continues to expand into studying

game design features that are beneficial to learning, the quality of the software is concurrently

improving. Gee (2007) proposed 36 learning principles that high-quality complex games have

that are used to engage and teach players. The principles are based around current research in

the field of gaming and can be placed into three subcategories. The first subcategory refers to

situated cognition, or the view that learning is not just a process confined to oneself but is fully

situated in a material, social, and cultural world. In this subcategory would fall the principles

that are focused on the embodied experiences and understandings in game-play that allow the

individual to practice, probe, and achieve through multiple routes. A second subcategory is

focused on *literacy*. In this group fall the principles that are based on incrementally piecing

together elements of the gaming experience to build a picture and develop meaning, often times

based on the player's intuition. The third group of principles is in *connectionism*, in which the

player begins the transfer of learned knowledge outside of the game. The expansion of the

semiotic domains is being built by the connection of DGBL behavior combined with previous

knowledge and continued experiences external to the game (Gee, 2007). Delivering these

strategies for learning via a DGBL platform can be beneficial to the learners of today and can

provide a means to engage students that are often lacking in traditional pedagogies (Hommel, 2010).

The ability for a game to provide instantaneous feedback and adaptive programming techniques, in which the difficulty level of tasks can shift depending on the user's progress, is another key feature that makes DGBL design attractive in the education setting (Prensky, 2007). Video games are designed for ready assessment. A player's skill level and mastery of a task is continually evaluated throughout game play, including multiple forms of feedback and an established reward system, often in terms of "unlocking" levels, items, or actions (Hommel, 2010). In digital learning environments, the player may not progress through levels until they have mastered a skill. In preparation for the assessment, input is delivered in a multimodal fashion, in which meaning and knowledge are built up through images, texts, symbols, interactions, abstract design, sound, etc. (Gee, 2007). Mastery is obtained through multiple methods of content delivery, making it obtainable and relevant, and prerequisite for the next challenge. If children are not given opportunities to practice their skills in ways that are deep or profound, they will not learn and potentially get stuck in a cycle of passive learning that they have no context for, therefore rendering the material inconsequential, meaningless, and ultimately forgotten (Gee, 2007; Prensky, 2007). By utilizing what is known about the way individuals learn, continuing to promote game design features that support delivery methods that engage and teach, and using research in the DGBL field, there is an impact that can be made on the education of 21st Century learners.

DGBL and neuroeducation. Research on how video games influence perceptual learning, cognitive load, and brain activity all have relevancy in the education of 21st century learners. According to the Henry J. Kaiser Family Foundation, 80% of individuals between the

ages of 8 and 18 multitask when using media; this was a 120% increase from the same age group a decade previous (Foehr, 2006; Rideout, Foehr, & Roberts, 2010). The ability to multitask involves both parallel processing and task switching, which can be efficient but simultaneously cost time and attention especially for new or cognitively demanding tasks (Palfrey & Gasser, 2008).

Adam Gazzaley, MD., Ph.D is a Professor of Neurology, Physiology, and Psychiatry at the University of California San Francisco campus, and the founding director of the Neuroscience Imaging Center. In the summer of 2005, Dr. Gazzaley opened a cognitive neuroscience research lab at UCSF, *Neuroscape,* with a goal to understand the neural mechanistic basis of cognitive control on the abilities of attention, working memory, and goal management through the use of technology enhanced learning. A major focus of the Neuroscape Lab is in the area of video game research, DGBL, and cognitive brain functioning. The studies were based on both consumer video games and closed-loop video games developed by the Neuroscape team and serve to determine the potential for developing increased cognitive functioning using interactive media. At a TEDx conference in January 2016, Dr. Gazzaley shared the mission of Neuroscape lab research and the results of video game trials on patients and how they enhance the functioning of the brain (Mishra, Anguera, & Gazzaley, 2016). He went on to discuss that the future of gaming has a role to play in the world of education, and that cognitive enhancement is not just something reserved for those in need, but as a way of improving brain functioning in healthy individuals as well (Gazzaley, 2016).

The field of neuroeducation is concerned with utilizing research findings in neuroscience and cognitive development to inform teaching and learning (Howard-Jones, Holmes, Demetriou, Jones, Tanimoto, Morgan, Perkins & Davies, 2015a). The collaboration of the sciences serves to

bridge the gap between researchers and teachers, and to construct meaningful relationships between neural processes and learning behaviors (Howard-Jones et al., 2015a). Research in the field of neuroscience does an excellent job of defining the areas of the brain that are active during recall activities and various performance tasks during DGBL, but caution should be used when trying to prove that this is proof of learning. Similarly, cognitive sciences have provided a lens in which to look at DGBL by placing emphasis on the output of correct responses within given time frames. However, memorizing and categorizing information does not equate to learning a concept, and only demonstrates a procedural knowledge base (Ross & Willson, 2012). The triangulation of neuroscience, cognitive science, and education theories lays a groundwork for the further development for DGBL.

The human brain is made up of over 100 billion neurons that serve the purpose of receiving and transmitting information throughout the nervous system. The synaptic activity and parallel processing that occurs around the clock is intricately adapted to respond to experiences and modulate accordingly (Cavanaugh, Giapponi, & Golden, 2016). A misconception regarding the brain is that it is a static entity and that it is hard-wired with its structure and function being biologically determined (Howard-Jones et al., 2015b). Brain plasticity refers to the idea that the structure, function, and connectivity change based on experiences and input from the environment. This perspective leaves room for redefining the ways in which learning happens, and how different types of multimodal neural processes support mental processes, which in turn influence behavior, creativity, collaboration, and agency (Howard-Jones et al., 2015b; Mishra, Anguera, & Gazzaley, 2016; Rubens, Zanto, Gazzaley, & Thangavel, 2011).

Traditional neuroscience equates learning with memory and looks at the patterns of change in connectivity between neurons (Howard-Jones et al., 2015b). There is evidence that

gameplay results in an increase in brain activity to specific areas of the brain and promotes cortical plasticity (Cavanaugh, Giapponi, & Golden, 2016; Green, Li, & Bavelier, 2010; Howard-Jones et al., 2015; Mishra, Anguera, & Gazzaley, 2016). Electroencephalography (EEG) is a method used by cognitive neuroscience and educational psychology researchers to measure brain activity by analyzing the electrical field generated by neural processing (Howard-Jones et al., 2015b). Brain activity during game play can be measured by EEG data to determine cognitive load by analyzing rhythms generated during synaptic processes (Howard-Jones et al., 2015b). The changes in the alpha and theta activity are related to activity in the information processing center of the brain; specifically, in the parietal and the frontal midline regions (Antonenko et al., 2010). Cognitive load can be measured by identifying separate, fluctuating components: instantaneous load, peak load, average load, accumulated load, and overall load; all of which paint a picture of an individual's mental effort (Antonenko et al., 2010).

The human brain continually generates, renews and reproduces synaptic transmissions between brain cells with the ultimate goal of creating an increasingly extensive and proficient neurological system based on experiences (Mondéjar et al., 2016). A recent mixed methods research study on video games and how they effected the development of cognitive processes related to executive functions (reasoning, self-control, and problem solving) used EEG analysis to determine fluctuations in brain activity (Mondéjar et al., 2016). The action video game elements of accurate action, timely action, mimic sequence, pattern learning, and logical puzzles were all used due to the different cognitive processes and skills required for each. The study focused on the electronic impulses in the brain and activity patterns that were generated by interaction with the elements individually and compared with participants (n = 12, ages 8-12, 6 boys/6 girls). The results of the study show that during game play, for many of the game design

mechanics, there is a noticeable increase in the activity of the prefrontal region that is related to executive functions (Mondéjar et al., 2016).

Neuroactivation is a term that refers to the areas of the brain that respond to changes in sensory stimuli, and is oftentimes measured by using functional magnetic resonance imaging (fMRI). In a recent research study a sample of novice computer users was compared to experienced computer users and neuroactivation was monitored to determine the difference among the more confident participants and those that were relatively new to gaming (Small & Vorgan, 2008). In this study fMRI data was used to identify the blood-oxygen-level dependent signals in specific brain regions, as users completed the same assigned experimental exercise. The findings showed that before the intervention the dorsolateral prefrontal cortex was much more activated for the savvy users than the inexperienced group. After 5 hours of gaming practice, the novice group was able to "rewire" their brain to perform a similar task, with comparable fMRI results. The significance of the neuroactivation in this region demonstrates that as neural networks are activated this may enable quicker reactions to visual stimuli and more rapid processing of large amounts of information (Cavanaugh et al., 2016; Small & Vorgan, 2008).

The potential for DGBL to impact neuroplasticity, accelerate learning, and strengthen cognitive function is evident based on empirical findings. Applications of DGBL and deliberate design that targets specific skills that crossover into the classroom is an area that research in neurosciences can help to inform. Although research in this field is still in its infancy and there is still much to be learned, the evidence of potential for targeted neuroactivation have paved the way for DGBL to make its way into education.

The State of Mathematics Education

In a 2008 report by the Mathematics Advisory Council, algebra was considered an important gateway to an increase in educational opportunities and later achievement in occupational futures. Preparation for algebra in the middle grades is crucial to student success in high school, and the opportunities that come with the world of higher level mathematics courses (Silver, 2000). A guiding resource for math teachers in the classroom is the National Council of Teachers of Mathematics (NCTM) *Principles and Standards for School Mathematics* (2000). Being able to use symbolic algebra to represent and solve problems, the ability to determine linear relationships, and manipulation of algebraic linear equations to maintain equality are some of the expectations outlined in the *Algebra* content strand (NCTM, 2000). According to the Common Core State Standards initiative mathematics education in the United States has been limited in the focus and clarity of the curriculum (CCSS, 2018). The standards stress conceptual understanding of key ideas, but continually revisit procedures throughout the curriculum to learn the procedures and laws that structure the ideas. In the Grade 7 band under *Expressions & Equations,* there are two standards that this research will address: a) use the properties of operations to generate equivalent expressions, and b) solve real-life problems using numerical and algebraic expressions and equations (CCSS, 2018).

Based on the number of low achieving students in the US compared with their international counterparts, policies started to shift to make algebra "The New Civil Right," highlighting the discrepancy between the students in remedial classes and those afforded the opportunity for algebra classes (Loveless, 2008).   In an attempt to provide greater access to algebra and to tackle the problem of mediocrity in math classrooms, policymakers urged states to implement algebra for all initiatives starting in middle school (Nomi & Allensworth, 2009). The

plan for this universal eighth-grade initiative was an attempt to create a sequence of classes from geometry (freshman), advanced algebra (sophomore), trigonometry or pre-calculus (junior), and finally calculus in senior year (Loveless, 2008). The rationale behind this movement was to level the playing field for all students with intellectually challenging course work to prepare them for college or work, especially in the growing STEM fields (Allensworth, Montgomery, Lee, & Nomi, 2009).

One of the key issues that has faced educators is that many of the students are limited in the adequate preparedness to take an introductory algebra course (Loveless, 2008; Vogel, 2008). A report from the Brown Center on Education Policy at the Brookings Institute gave an account of the 120,000 misplaced 8th graders (that is, enrolled in algebra classes they had no basic skills for) scoring in the bottom 10 percent of students nationwide on a NAEP math test (Loveless, 2008). These students were lacking basic arithmetic skills, and struggled with items that involved basic fractions, decimals, and percentages (Loveless, 2008). Teachers have reported experiencing difficulty accommodating instruction and being able to give sufficient attention to meet the needs of low-ability students (Nomi & Allensworth, 2009). This lack of procedural understanding is one of the factors that makes the jump to algebra a challenge.

Multiple studies on large urban districts and the universal mandate for increased rigor concluded that there have been several major unintended consequences, including: 9th grade mathematics grades declining, especially among average-ability students (0.18 percentage points; $p < .05$); math failure rates increasing among average-ability students (8.9 percentage points; $p < .05$) and low-ability students (3.0 percentage points; $p < .01$); and absenteeism among average-ability students increasing (1.6 more days; $p < .05$) (Allensworth et al., 2009; Domina, McEachin, Penner, & Penner, 2015; Loveless, 2008; Nomi, 2012; Nomi & Allensworth, 2009).

A 2006 study from Florida International University found that students who failed first year Algebra were four times more likely to drop out of high school than those who passed. The question has been posed if the increase in standards and requirements are to blame for pushing students out of school altogether, and if it possibly the case, how can educators supplement the curriculum to address the needs of the students? (Vogel, 2008).

For the scope of this research, two long-term outcomes that have stemmed from the one-size-fits-all approach to algebra instruction are that: (a) students have become less engaged in mathematics instruction; and (b) procedural operations (lower-level) have been the focus of mathematics, rather than concept building (higher-level) (Arcavi & Friedlander, 2012; Star, 2005). Much of the research supports the idea that the limited motivation, coupled with a lack of context with which to apply procedural understanding, is not a recipe for success in the Algebra classroom (Arcavi & Friedlander, 2012; Star, 2005).

Problem solving: procedural and conceptual knowledge. For many students, Algebra 1 is the first class that requires critical thinking and the ability to problem solve (Vogel, 2008). The term problem solving has come to have broad meaning in the context of a school math class. Early educational research focused on the heuristics of problem solving or the techniques that help problem solvers to understand or to solve a given problem (Voskoglou, 2012). More recent work in the field has focused primarily on the identification of attributes that characterize a successful problem solver and the meaningfulness of integrating procedures and thinking processes. According to mathematician George Polya, problem solving is made up of four basic principles: understand the problem, devise a plan, carry out the plan, and reflect (Polya, 1963; Voskoglou, 2012). To problem solve, one must look for ways to overcome given obstacles by using critical thinking skills that are based on of the application of old or learned knowledge

applied to new situations. Mathematical problem solving is an area in which algorithms and formulas are often taught out of context, and many students are left with an inability to critically think their way through the manipulation of an equation to solve new problems. The amount of emphasis placed on teaching content knowledge in the form of textbook and lecture-based formats is effective for a handful of learners, but tends to leave behind those that have learning systems in which information needs to be delivered using non-traditional methods (Ross & Wilson, 2012; Voskoglou, 2012). Limiting the context to an algorithmic problem solved with a series of prescribed steps, the transfer to a new problem or situation becomes impeded. While this may be the case for many learners, there is still not a clear consensus on the respective roles of procedural and conceptual understanding (Star, 2005). Algebraic concepts draw heavily upon procedural skills that students develop in elementary mathematics and require those proficiencies to develop a new set of abstract reasoning skills (Domina et al, 2015). The fields of cognitive and developmental psychology have focused extensively on the relationship between procedural and conceptual knowledge and their roles in mathematics education (Star, 2005). Preparing students to make the transition from elementary arithmetic skills to abstract ideas requires deliberate changes in pedagogy that includes algebra readiness instruction (Vogel, 2008). Strategies suggested to improve student performance have included implementation of technology curriculum, instructional changes, use of manipulatives, and the focus on developing conceptual understanding (Rakes, Valentine, McGatha, & Ronau, 2010).

An approach to developing problem solving that has been proposed by research in the field of mathematical thinking is a blend of both the conceptual and procedural processes (Friedlander & Arcavi, 2012; Rakes et al., 2010; Ross & Wilson, 2012). Constructivist theories about the ways in which students acquire knowledge describe an environment where an

individual creates their own learning through active engagement in problem-based situations (Illeris, 2009; Voskoglou, 2012). Algebraic problem solving requires a balance between procedural and conceptual understanding (Ross & Wilson, 2012). These are two diametrically opposed philosophies about the orientation of mathematics: the *formalistic-productive* and the *intuitive-inductive* (Voskoglou, 2012). While the former deals strictly with content and procedure, the latter's attention is on the conceptual problem-solving processes.

Having a terminological framework for discussing aspects of mathematical knowledge was initially proposed by Hiebert & Lefevre (1986). Without a referent between professional educators to describe outcomes, it would be difficult to articulate mathematical learning goals, the attainment of goals, and the method of which these goals can be assessed (Star & Stylianides, 2013). For purposes of this research, the two-fold definition that will be used for procedural knowledge is:

> One kind of procedural knowledge is a familiarity with the individual symbols of the system and with the syntactic conventions for acceptable configurations of symbols. The second kind of procedural knowledge consists of rules or procedures for solving mathematical problems. Many of the procedures that students possess probably are chains of prescriptions for manipulating symbols (Hiebert & Lefevre, 1986, pp. 7-8).

Conceptual understanding is a deeper level that involves the networking of ideas, and applications of mathematics to new situations. It is developed through prior knowledge in which students can compare new ideas with old ideas, and use generalizations to discover new theorems or proofs (Ross & Wilson, 2012). Conceptual knowledge is defined as:

> … knowledge that is rich in relationships. It can be thought of as a connected web of knowledge, a network in which the linking relationships are as prominent as the discrete

pieces of information. Relationships pervade the individual facts and propositions so that

all pieces of information are linked to some network (Hiebert & Lefevre, 1986, pp. 3-4).

Rethinking the ways in which algebraic skills are taught should include methods that guide the

students from concrete arithmetical concepts to abstract thinking and problem solving

(Friedlander & Arcavi, 2012; Vogel, 2008). Algebraic relationships encountered outside of the

classroom will not present themselves as a series of equations requiring manipulation of symbols

and variables. They will present themselves as decisions involving matters that require real-time

problem solving, long-term planning and application of conceptual knowledge. Procedural

understanding is the tool to solve problems and represent situations, and without connections the

procedures can prove meaningless.

In a comprehensive literature review on methods of instructional improvement in algebra,

82 relevant studies with 109 independent effect sizes representing a sample of 22,424 students

were covered (Rakes et al, 2010). One of the purposes of the wide-ranging study was to

establish which characteristics of teaching interventions in algebra have the most impact on

determining the effectiveness of the intervention on student achievement. The research identified

two of five categories of thematic interventions specific to technology (technology curricula and

the use of technology) used to improve algebra achievement in middle school classrooms. Both

of these categories resulted in positive weighted average effect sizes that were statistically

significant in at least one analysis model ($p < 0.305$ and $p < 0.073$, respectively). In addition to

the intervention categories, researchers looked at the breakdown of interventions intended to

target conceptual understanding (31%), while the remainder of the studies examined

interventions with procedural understanding. According to the analysis between the conceptual

and procedural studies in the sample, the conceptual studies produced a statistically larger

average effect size on student achievement ($d_{conceptual}$ = 0.467, SE = 0.099, p = < .05; $d_{procedural}$ =

0.214, SE = 0.044, p = .05). Although procedural understanding interventions are much more

familiar to teachers and more similar to traditional teaching methods, they should be blended

with conceptual pieces for optimal academic growth. According to research over the span of

decades, the use of technology as part of the algebra curriculum aids in the development of the

foundational understandings of abstract reasoning, language acquisition, and mathematical

structure; all which can be critical to enhancing academic achievement (Rakes et al, 2010). The

conceptual emphasis embedded in interventions and scaffolds further benefits the learner by the

improved ability to adapt to unfamiliar situations, engagement in meaningful mathematical

discussions, the reduced need to memorize rules and heuristics, and the increased intrinsic

motivation to learn mathematics (Friedlander & Arcavi, 2012, Rakes et al., 2010).

In order to address the lack of procedural and conceptual algebraic understanding that

many students have, pilot studies have been undertaken in which visual diagrams with

accompanying software is used to present ideas in new and accessible ways (Vogel, 2008).

Using DGBL as a supplement in classroom teaching has the potential to lay a foundation for the

goal of critical thinking development. The MIND Research Institute has reported collaborative

research findings on the visual game-based math, the improvement of fluid intelligence with

DGBL training on working memory, and motivational effects from cognitive training (Wendt &

Rice, 2013). Post-hoc analysis on a population of 19,980 second through fifth grade students

from 129 schools using Spatial-Temporal (ST) visual conceptual instruction in a DGBL

environment was conducted (Wendt & Rice, 2013). The demographics of the study included

72% low income, 66% Hispanic, and 6% African American students, and excluded schools in

the category of *high-performing* based on California Department of Education criteria.

Proficiency level percentages were based on the California Standards Tests (CST) Math from the baseline of 2009 and 2010 as reported by the California Department of Education. There was a statistically significant gain in *Proficient* or *Advanced* students who scored on the average 6.38 percentage points higher than students in comparison grades ($r = 0.47$). Additionally, the proportion of students in each grade scoring *Advanced* made gains of 5.58 percentage points compared to non-treatment population ($r = 0.40$) (Wendt & Rice, 2013).

Camli and Bintas (2009) conducted a quantitative experimental study with a pre- and posttest design to determine the academic achievement of students using computers. Their study included 102 sixth-grade students in a public elementary school over a 5- week period. They used computer software designed to assist students in mathematics problem solving. Camli and Bintas found the experimental group that used the computer software for mathematics problem-solving support performed significantly higher on the posttest than the control group, which had no computer usage.

The Role of Motivation in Mathematics

Educational psychology has long been concerned with research on how learning and achievement are influenced by cognitive and motivational factors, and interconnected with individual and situational interests. Where mathematics is concerned, special attention is focused on how to best develop approaches that foster curiosity, attention achievement motivation, and intrinsic motivation (Krapp, 1999). For the purposes of this study, Schunk's (1990) definition will be used to refer to motivation as the desire and willingness to employ effort toward and persist in the learning task. Motivation is influenced by several factors (*e.g.,* attention/interest, relevance, confidence, satisfaction, goals, etc.), and lack of attention in the

design of instructional material and school environment can lead to declines in motivation and academic achievement (Belland et al, 2013; Hidi & Harackiewicz, 2000).

Perhaps in relation to the limited relationship between procedural and conceptual understanding comes limited engagement and interest in the mathematics task at hand. The foundational understandings of algebra involve participating in problem solving and abstract reasoning, translating the foreign language of mathematical symbols, and learning the structural characteristics of algebra (Rakes et al., 2010). The triangulation of these three challenges pose an obstacle to learning for many students, and create an experience that is unengaging, and provides very little in the form of a positive experiential state. Creating a culture of mathematical inquiry in the classroom can only take place when students have had exposure to cognitively accessible content with which to draw from (Rakes et al., 2010). Davis (1992) observed that

> With the best of intentions, we have created a curriculum of mathematics that has been severed from the real-world. It consists of meaningless bits and pieces, and we asked students to learn it as a larger collection of meaningless bits and pieces. (p. 730)

Interests and goals of students have long been thought to be important motivational variables that impact academic performance (Hidi & Harackiewicz, 2000). The limits of motivation have heavily impacted academic achievement of a majority of students today. In a National Research Council (1989) report on the future of mathematics, it was noted that, "Mathematics is the worst curricular villain in driving students to failure in school. When mathematics acts as a filter, it not only filters students out of careers, but frequently out of school itself" (p.7). One of the key issues in the mathematics classroom is the need for an enhanced interest among the students. Without seeing the content as useful for their futures, the level of

interest and engagement is inadequate for persistence in mastering the content (Allensworth et al., 2009). Research on the outcomes of mandating more challenging mathematical content to students who lack the necessary procedural skills to develop conceptual problem solving is that the courses are beyond the capabilities of many students, and therefore not helpful (Allensworth et al., 2009). Motivational design that is grounded in theory and practice and that uses supplements to scaffold learning have outcomes that promote knowledge creation (Belland et al, 2013).

Multi-dimensional views on the effects of internal and external factors that impact the learning environment offer a framework to facilitate motivation and learning. There are many theories of motivation that identify necessary attributes of the learning experience, that include interest, attention, relevance, confidence, and satisfaction (Weppel et al, 2012).

Attention and developing mathematical interest. According to educational research on motivation, interest is a key area that influences a student's academic motivation. In 1913, Dewey laid the groundwork for motivation in the classroom by providing the following,

> Genuine interest is the accompaniment of the identification, through action, of the
>
> self with some object or idea, because of the necessity of that object or idea for
>
> the maintenance of a self-initiated activity, which is an essential component of
>
> interested behavior (p.14)

Based on Hidi and Harackiewicz's (2000) work on academically unmotivated students, interest was defined as "an interactive relation between an individual and certain aspects of his or her environment (e.g., objects, events, ideas), and is therefore content specific" (p. 152). Researchers have identified three conceptualizations of interest which lay a foundation for discussions on academic motivation: (1) interest as a personality trait, (2) interest as a

characteristic of the learning environment, and (3) interest as a psychological state (Krapp, 1999). Interest as a disposition can be seen either as having dependent or independent variables within a network of interrelated factors, and is related to psychological interests. It can further be broken into two subgroups: *individual* and *situational* (Hidi & Harackiewicz, 2000). Individual interest is thought to be a disposition that develops over a time period in relation to a specific topic or domain. Characterized by increased knowledge, value, and positive feelings, individual interests are relatively stable. In contrast is situational interest, which is generated by conditions in the environment that focus attention, but may not sustain the reaction of the individual. Generally, in order for a person to attain individual interest, they are exposed to a stimulus in which they experience situational interest. Certain facets of the learning environment can contribute to the development of situational interest by addressing personal relevance of material and providing opportunities to explore through different learning systems. *Undivided interest* is a synthesis of cognitive qualities (focused attention, meaningful thoughts, perceptions of importance to self) and positive affective qualities (feelings of enjoyment) that contribute to individual interest and intrinsic motivation (Hidi & Harackiewicz, 2000). A goal of a DGBL environment is to develop the affective qualities of enjoyment and engagement, that in turn would allow the student to experience the cognitive qualities that will be supported and transfer into the non-gaming world.

The expression *catch and hold* describes a condition that DGBL has been shown to have affected (Gee, 2007). In the situational interest model proposed by Mitchell (1993), the term "catch" was used to relate the different ways in which to stimulate students with the positive affective qualities, while "hold" refers to the relevant variables that can empower students and challenge them with cognitive qualities. Methods to stimulate students, and catch their attention

include group work, computers, puzzles, and games. In order to maintain student interest, there needs to be meaningfulness and involvement in the activity (Mitchell, 1993). In the *catch and hold* phenomena, the two components work together to develop the type of situational interest that is sustained over time and transforms into a type of externally controlled motivation (Hidi & Harackiewicz, 2000; Mitchell, 1993). Whereas individual interest is seen as a pre-condition of intrinsic motivation, held situational interest is a pre-condition of individual interest (Hidi & Harackiewicz, 2000). For the purposes of this study motivation will be addressed by the subcomponent of *interests.*

   Relevancy of mathematics. A common assumption among educators is that by the mere presence of authentic, problem-based experiences, students will automatically be motivated to engage in learning (Belland, Kim, & Hannafin, 2013). In order to build confidence, students need to have learning accessible to their individual learning systems and to have a sense of perceived learning. One of the methods by which content can be delivered to diverse groups of learners is through the use of scaffolding, which in its original application to educational contexts was equal parts motivational and cognitive support. Scaffolding is defined as "contingent support that structures and highlights the complexity inherent in problem solving, thereby supporting current performance and promoting skill gain" (Belland, Walker, & Kim, 2017, p.1043). As tasks become manageable and expectancies for success are met, student motivation increases. Internal scaffolds embedded within tools used for learning, and external scaffolds that appear through instruction can be used to increase the willingness of students to engage in complex tasks, and can supplement the traditional curriculum (Belland et al., 2017; Belland, et al, 2013).

Satisfaction and goal-setting. An area of further research with DGBL and motivation is to explore the relationship with achievement goals. Categorized into task involved versus ego involved, learning oriented versus performance oriented, and mastery focused versus ability focused, different types of goal orientations have different motivational processes that are associated with them (Ames & Archer, 1988). The conceptual relationship between these goals have integrated into one another, so a broader approach looks at mastery and performance goals as the overarching structure (Ames & Archer, 1988). In non-DGBL studies, students who perceived importance of mastery goals, as opposed to performance goals, reported using more effective strategies, preferred tasks that were more challenging, had a positive outlook on their learning environment, and maintained a stronger belief in the positive correlation between success and effort (Ames & Archer, 1988). Satisfaction describes the learners' overall evaluation of the learning experience and the intended outcomes (Weppel et al, 2012). Oftentimes satisfaction is addressed by the variable of individual goals in which mastery goal orientations lead to the engagement in challenging tasks to develop procedural and conceptual understanding (Belland et al., 2013). Satisfaction can be in the form of personal learning goals or as reward systems built into the games. Many educational video games are designed to have an extrinsic reward system as part of their attempt at motivation (Gee, 2007; Hainey et al., 2016). Built in systems of rewards that help guide the player to task mastery include unlocking characters/levels/items, accessing controls, bonus points, leaderboards, etc. The selected DGBL platform used for this study (Dragonbox Algebra 12+) lacks many of the extrinsic reward systems that tend to encourage a performance goal oriented environment (leaderboards, customizable avatars, competitive play). To control for this variable, the game itself will

function as a reward that attempts to deliver situationally interesting activities to aid in educational intervention.

Research has been inconclusive as to which type of mastery goals (intrinsic or extrinsic) are more beneficial to academic achievement, but most studies confirm that both factors contribute to motivation, persistence, and deep processing (Belland et al., 2013; Hidi & Harackiewicz, 2000). When looking at goal research, the argument of goals being the byproduct of interests are diametrically opposed to the school of thought that promotes that interest is developed through the integration of a goal structure (Hidi & Harackiewicz, 2000). In addition to emotional feedback and the subjective experiences during the experience, Krapp (1999) maintains that the development of interest is controlled through "cognitive-rational processes of intention formation or the deliberate selection of learning goals" (p.33). The relationship proposed basically builds a psychological state within a person with input from characteristics of the learning context (interestingness) and characteristics of the person (individual interest). The developed situational interest can then develop into personal, and longer-lasting interest in a particular content area. Highly motivated and engaged students are more likely to experience success in the classroom (Dev, 1997).

Game Design for Education

Well-designed games integrate learning content within the narrative and mechanics of the game, while also creating opportunities for motivating and providing meaningful learning (Barzilai & Blau, 2014). To translate the explicit understandings into knowledge through a DGBL experience, some games have included components of scaffolding that integrate informal knowledge representations, and serve to create connections to more formal concepts. One of the key challenges in implementing DGBL in the classroom is assisting the children in making

connections from what they experience during game play and applying it to what they are learning in school. Without identifying the semantics, the cognitive foundation necessary to develop concepts is absent, and the tool (game) quickly transforms into a meaningless object (Prensky, 2007). The disconnect of semantics is where the role of the game is put under scrutiny for its educational value and the types of learning that are being promoted by dedicated time during a gaming session.

Not all DGBL looks the same, nor have the same intended outcomes, but tend to incorporate key elements of learning, including logic, memory, problem-solving strategies, and critical thinking (Rosen, 2010). Games are typically designed with six features in mind to promote learning: (a) rules; (b) goals and objectives; (c) outcomes and feedback; (d) conflict, competition, challenge, or opposition; (e) interaction; and (f) a storyline (Prensky, 2007). These characteristics vary in their game presence, but a gaming activity holds consistent to being a contest of skills and strengths, requiring the player to follow a specific set of rules to achieve a goal (Nachimuthu & Vijayakumari, 2011). In order for DGBL to be impactful, there needs to be feedback to the player when they have mastered a goal during gameplay.

In the semiotic domain of the gaming environment, the design helps the player to learn in an active manner and has the potential outcomes of: (a) experiencing the world (virtual and real) in new ways; (b) forming affiliations with others who share the experiences; and (c) gaining resources that prepare for future learning and problem solving in the domain and related domains (Gee, 2007).

Research in the field of game development looks at two cognitive principles: competence-based and expertise-based (Rice, 2007). The intense learning situations that players are immersed in that lead to a conclusion in game play help to develop competence. In a

classroom environment, this might take the form of fluency with math facts or fluency with a passage of literature. Completing tasks based on a set of rules and mastery of gaming elements helps to develop expertise, leading the way towards increased opportunities for problem solving (Rice, 2007). In this this phase, situated meaning is applied to the competency elements, and the player is actively learning how to apply the meanings in new situations in the virtual world (Gee, 2007). Expertise, when applied in the context of learning, would be evident in the application of skills in which the individual has attained competency, contributing to the self-efficacy of the student. As a supplement to classroom teaching DGBL can guide the student towards actively learning and ultimately developing critical thinking skills. As students become innovative with deconstructing their knowledge into interrelated parts that make up the more complex system, they are building a more robust understanding (Gee, 2007; Prensky, 2001).

Transfer of knowledge from DGBL. Many games used in a DGBL environment make extensive use of symbols and other abstractions. In order for the learner to use the symbols and strategies to form hypotheses, make connections, and experiment they need to understand the symbolic meaning behind the representations (Shin et al, 2012). Dedre Gentner's (1983) Structure-Mapping Theory (SMT) will provide a framework in order to better understand how DGBL can impact academic achievement and the problem solving abilities of individuals by drawing connections between representations and understanding. While there are multiple ways in which individuals problem solve and think in complex and novel situations, SMT addresses the forms of cognition that are based on similarity (Bach, 2011; Nokes, 2004). This theory is built upon the idea that people use and adapt their prior knowledge to solve new problems by use of analogical transfer (Gentner, 1983). Gentner describes analogical transfer as: the comparison that normally applies in one domain can be applied in another domain when little to no object

attributes can be mapped from one representation to the other. Analogical transfer is composed

of three sub-processes: (a) receiving a prior knowledge structure, (b) creating a mapping between

it and a new problem, and (c) developing a new and contextually relevant structure based on the

mapping (Nokes, 2004). According to SMT, the representations are mutually aligned and

knowledge is generated through their shared features (Bach, 2011). In this type of relationship,

there is an overlap in the relations mapped to the target, but not the attributes (Gentner, 1983). In

the DGBL transfer scenario, activities that are representative of components of linear equations

will be introduced through a video game. This interaction between the gaming elements in a

representative situation will provide a framework for which students transfer their understanding

of the procedures for solving equations into the math classroom. In the context of Dragonbox

Algebra 12+, the iconic representations are the pictures (boxes) used in the game, they are

manipulated by a set of algebraic principles (shared features), and transformed into a new

knowledge structure. Gee (2007) described this, in the context of DGBL, as a set of nodes that

associate images (patterns) from our virtual experiences from media and conceptual elements.

When a learner plays a game that uses representative images and symbols to teach, theoretically,

they will be able to transfer that learning to an algorithmic formula.

  Integrating DGBL within the formal classroom environment requires the students to

make connections between the knowledge learned in the game and the knowledge learned at

school. In a study on how learner supports might be more systematically incorporated in DGBL,

Cates and Bruce (2000) designed a Model of Scaffolding for working within a computer

instruction environment. The conceptual model was designed to find the best possible supports

to address motivational and cognitive needs of a diverse range of learners, and has been used in

educational game design. In her work on human-computer interface design, Nicol (1990) suggests that:

> In designing new tools for learning, we need to be familiar with more than just the content of the application. We must also learn to appreciate the ways in which learners construct new concepts so that we can design interfaces that at least support and perhaps even enhance those learning processes. (p.122)

Whereas early pioneers in the educational software development industry looked at two components for embedding support systems: (a) interface guidance on using the program properly, and (b) content guidance on "passing" or "completing" challenges within the game; more current research expands on the supports. Cates and Bruce (2000) have identified three types of learner supports: support in optimizing use of the program (procedural guidance), (b) support in learning the content of the program, and (c) support in monitoring and transferring the learning (metacognitive guidance). DGBL design uses methods based in the analogical transfer of representative icons and design features embedded into the interface, to provide the best possible outcomes for connections from game to classroom (Cates & Bruce, 2000; Gentner, 1983; Prensky, 2001).

Li and Ma (2010) conducted a meta-analysis to determine students' learning of mathematics with the use of DGBL. Included in the meta-analysis were doctoral dissertations and research articles from 1990-2010 that focused on the K-12 classrooms. The selection criteria included a three-step approach with 100% interrater agreement as to which studies and articles would be represented in the meta-analysis. Li and Ma (2010) found that there was an overall positive effect of computer technology and exploratory environment (DGBL) on mathematics achievement.

In a small-scale, long-term mixed-methods study involving the use of computer-based mind games (e.g. puzzles, brainteasers) Bottino and Ott (2006) evaluated the cognitive skills that were required in several educational computer games and how they impacted school performance in mathematics. The 4th grade math students that were part of the experimental groups played five games that involved the cognitive skills of: (a) learning to analyze data to reach a goal; (b) learning to formulate and verify a hypothesis; (c) learning to anticipate with given data; (d) learning to conceive a solution strategy; and (e) learning to use feedback to revise work. Based on the pretest/posttest measures, the treatment groups (Class A and Class D) showed an increase in their academic achievement compared to the control groups (Class B and Class C) based on the results of the INVALISI (Italian Educational Institute) mathematics test. Means (with standard deviations in parentheses) for Class A through Class D were 72.80 (15.87), 53.57 (16.86), 56.55 (18.99), and 63.03 (21.43), respectively. The two-stage analysis included a detailed *a priori* examination of the games and then direct observation of the students at work in the DGBL environment. Based on the observations, it was reported that the students in the treatment groups displayed a positive impact on their overall abilities in thinking skills, logical reasoning, and strategic thinking.

In a 4-month study of 50 second grade students, Shin, Sutherland, Norris, and Soloway (2012) investigated data sets to explore performance in mathematics and determined a relationship between DGBL and procedural knowledge in arithmetic. In the quasi-experimental control-group design, repeated measures ANOVA revealed that DGBL was beneficial to students of all ability levels in learning math skills. In determining how performance changed over a period of time with increased frequency of DGBL sessions per week, a portion of the study enabled researchers to compare the gains in scores of the groups from 5-week and 13-week

periods. The results of the ANCOVA revealed that students who interacted with the game more frequently had higher performance than those who played it less often. Statistically significant results confirmed that a DGBL environment can positively impact mathematical learning and can be an effective tool for student success (Shin et al., 2012).

Research in the field of problem solving and conceptual understanding has proposed the incorporation of problem-posing in order to develop skills and actively engage in mathematics (Baxter, 2005; Friedlander & Arcavi, 2012; Voskoglou, 2012). In 2012 Chang, Wu, Weng, & Sung explored the phases of problem-solving in a DGBL system for mathematics learning. The multi-phase process, based on Polya's problem solving principles, used by the researchers included posing a problem, planning, solving the problem, and reflecting on the solution (Chang et al., 2012). In the study the problem solving portion of the process was completed in a game-based scenario for the experimental group, compared with a traditional paper-based approach. There were statistically significant differences in the overall scores in relation to problem-posing ($F = 17.69$, $p < .01$), accuracy ($F = 24.4$, $p < .01$), flexibility ($F = 22.36$, $p < .01$), elaboration ($F = 10.42$, $p < .01$), and originality ($F = 11.39$, $p < .01$). The results also showed that students with lower pretest scores were more likely to improve in problem-solving, equation-listing, and in calculation. In addition, many of the students from the experimental group showed an increase in flexibility (from using one problem type to integrating two problems types), and in mathematical vocabulary (Chang et al., 2012).

Research in the field of transfer from digital environments to the classroom content continue to uncover some important evidence for building supports within DGBL. Continued research on how best to transfer the learning in a math classroom from, not only, DGBL to problems, but from a basic procedural understanding to a more conceptual knowledge base is

needed. This research study will explore the DGBL environment as supplemental to a traditional math class to support building a base in algorithmic understanding, combined with a project-based environment to utilize the conceptual approach, and determine if the triangulation has a significant effect on understanding.

DGBL to enhance motivation. The quandary that many educators face is the importance of promoting the engagement of students in authentic problem solving, which often may not produce the desired results on measures that emphasize declarative knowledge. Many educational researchers agree that some of the most effective instructional approaches, including project-based learning, problem-based learning, inquiry-based learning, and design-based learning, can produce both conceptual and procedural type solutions, as well as increase student motivation (Belland, Walker, & Kim, 2017). Computer-based scaffolds embedded within the DGBL software complement teacher scaffolds within their classroom instruction. This scaffolding has been proposed as a method by which to potentially bridge procedural knowledge with conceptual knowledge and increase motivation (Belland et al. 2017). Well-designed DGBL scaffolding supports motivational variables such as students' self-efficacy, autonomy, connectedness, mastery goals and perceptions on the relevancy of the target task, and assists in the enhancement of domain knowledge and higher order thinking skills (Belland, Walker, Kim, & Lefler, 2017). Looking at the role of technology in the classroom and the potential to utilize DGBL effectively has led to research in the design of systems that employ scaffolding strategies that help students (a) identify variables to consider when approaching a problem, (b) design a method to address the problem, (c) analyze their solution to the problem, (d) enhance interest, self-efficacy, and motivation variables.

Belland, Walker, Kim, and Lefler (2017) synthesized results from 144 experimental studies on the effects of DGBL platforms that utilized scaffolding interventions (conceptual, metacognitive, motivation, and strategic) in their design, and were specifically targeted towards STEM education. Results of the meta-analysis indicated that DGBL software showed a positive effect ($g = 0.46$) for a wide range of learner populations, cognitive outcomes, and across a variety of contexts. Scaffolding interventions were categorized into conceptual, strategic, metacognitive, or motivational, with Hedge's g significantly greater than zero across all types, and with no statistically significant differences among the types ($p > .05$). In a similar meta-analysis of 56 studies, Belland, Walker, & Kim (2017) looked only at the computer-based scaffolds that specifically targeted cognitive outcomes in STEM education. It was determined that scaffolding led to strong pre-post gains in the assessment categories of concept ($g = 1.79$), application ($g = 1.93$), and principles ($g = 2.3$). While the types of computer-based scaffolds ranged from generic to specific, it was evident from the studies that designers and educators would choose their targeted scaffold based on the learning needs of the student, and the skill to be learned.

Research in the field of DGBL and motivation looks to tackle different variables by analyzing the effects of game genre, learning outcomes, and targeted subject area. Video game experience is effective in psychologically motivating and physiologically arousing players, compared with standard psychophysical tasks (Green et al, 2009). With engagement and motivation at the forefront of DGBL design, researchers warn that marketing and development have capitalized on the stimulation facet of interest with the educational games that contain simple novelty distractions that catch the player's attention but fail to hold their interest over

time. The Dragonbox Algebra software employs many of the embedded scaffolding techniques specifically intended to improve motivation, engagement, and cognition.

Papastergiou (2009) performed a quantitative, quasi-experimental study with a pre- and posttest design to measure the impact on educational effectiveness and student motivation in response to DGBL intervention. The researchers developed a game that shares many of the same characteristics and features as the Dragonbox Algebra software. The design elements that promoted student involvement within a DGBL environment were adopted: (a) rules, (b) clear but challenging goals, (c) a fantasy scenario linked to student activity, (d) progressive difficulty levels, (e) interaction and high degree of student autonomy, (f) uncertain outcomes, (g) immediate feedback (Papastergiou, 2009). The intention of the design was that it be was neither too complicated nor too easy, based on the student's existing knowledge of the content. Two randomly assigned groups were created from the population ($N = 88$) of high school computer science students that would be completing a curriculum on computer memory concepts. The treatment group ($n = 47$) used the DGBL application for a total of 2 hours during the multi-week intervention, while the control group ($n = 41$) would be working on a non-gaming digital application. The results of the ANCOVA indicate that there were statistically significant main effects based on the intervention types on the Computer Memory Knowledge Test (CMKT) posttest in favor of the treatment group [$F(1,83) = 8.853$, $p = .004$]. The students that used the gaming application performed significantly higher than those who had used the non-gaming digital intervention. The data gathered through a multi-dimension feedback questionnaire revealed that students in the treatment group found the DGBL intervention more appealing, of more educational value, and the learning material more accessible than traditional instructional techniques (Papastergiou, 2009).

In a comprehensive meta-analysis on the effects of DGBL, Hainey, Connolly, Boyle, Wilson, and Razak (2016) categorized 105 studies conducted between 2000 and 2013. Using a variety of game genres (strategy, adventure, role-playing, puzzle, simulation, action, virtual reality, virtual world, and generic/non-specified), the researchers further categorized the games into educational subject areas and learning outcomes. Six of the total games for learning were analyzed for their impact on affective and motivational change, which lends to the research gap that this study will address. The results of these investigations are discussed further individually.

In an investigation on intrinsic integration in educational games in relation to motivation, Habgood and Ainsworth (2011) studied the effects of an adventure-based math game in a Randomized Controlled Trial (RCT) study. In their study of the comparison of time on task for intrinsic and extrinsic variants in *Zombie Division*, a paired-samples *t*-test revealed statistical significance ($p < 0.001$) that participants (n = 58, *M* = 8 years, 0 months) spent 7 times longer playing the intrinsic version of the game (*M* = 75.7 min, *SD* = 35.5) than the extrinsic version (*M* = 10.28 min, *SD* = 10.28). In addition, children learned more from the intrinsic version of the game, as reported by their pretest and posttest scores.

Kuo (2007) examined how DGBL promotes motivation to learn science, by using a strategy genre game on 3rd grade students over a period of two weeks. Two classes were randomly assigned to a control group (using a multimedia learning environment) or the experimental group (using a DGBL environment). The results showed significant improvement in interest in learning science in the DGBL environment and successfully motivated participants in developing individual interests in science (exploring natural science and engaging in learning). Based on the quantitative and qualitative results it can be concluded that although the DGBL

environment does support an increase in interest, there was not significance between the learning outcomes of the two groups.

In their research on the effect of DGBL on motivation, Wang, Tsai, Chou, and Hung (2010) used a randomized controlled trial approach with a strategy-based game that targeted a variety of learning outcomes. A total of 124 6th grade students was divided into a control group (non-DGBL environment) and experimental treatment group (DGBL environment). There were significant differences in learning motivation of the DGBL participants, yet learning achievement and reasoning abilities between the groups were not significantly impacted. In their discussion, the researchers speculated that the motivation to play the game outweighed the concentrated effort given on the paper-based tests. There was a positive correlation between the level of motivation and children's learning; and inversely, low motivation led to low productivity.

Summary

DGBL has been researched in terms of cognition and neuroscience, its impact on problem solving abilities and the effect that it has on student motivation. Outside the scope of this study, DGBL has been studied to determine the impact on learning based on variables such as collaborative play (Plass, O'Keefe, Homer, Case, Hayward, Stein, & Perlin, 2013), the development of serious games (Michael & Chen, 2006; Sanford et al, 2015), classroom management (Bayart, Bertezene, Vallat, & Martin, 2014), and improvement to cognitive deficits (Mishra et al, 2016), among many other domains. As shown in this literature review, there are many theories of learning and research-based studies that have demonstrated the use of technology as a means of accomplishing the task of meeting the needs of 21st century learners. Research has shown that the use of DGBL is not only a much-needed practice in education but

also has the potential to increase motivation. The use of DGBL to supplement the curriculum, foster motivation, and support academic achievement is an area that needs to be researched further with the use of internal and external scaffolds to facilitate transfer.

This chapter has outlined the current literature on educational theories and learning paradigms, DGBL's impact on cognition as put forth by the field of neuroscience, the role of conceptual and procedural understanding in mathematics, transfer of knowledge through representative structures and scaffolding, and motivation towards learning. Chapter Three, Methodology, will highlight the chosen research methods, as well as describe the characteristics of the study and the participants.

Chapter Three: Methodology

This chapter includes a rationale for the methodology: description of the participants and the setting, background of the digital game used in the study, design and procedures, instruments used to measure growth, and ethical considerations. By utilizing a mixed methods approach, this research determined the impacts of DGBL on procedural and conceptual knowledge skills in mathematics and their motivation towards mathematics instruction. As part of a STEM class (in addition to math class) groups received supplementary interactive digital learning through frequently used platforms for the control group and a game-based approach for the treatment group.

Research Question and Hypotheses

The purpose of this study was to investigate the effects of Digital Game-Based Learning (DGBL) on procedural and conceptual mathematical skills and motivation of seventh grade math students. The research questions driving the study are:

1. How does digital game-based learning impact procedural and conceptual mathematical understanding among students?

2. How does digital game-based learning affect learners' motivation towards classroom mathematics?

The specific hypotheses for the study were:

H.1 Students playing Dragonbox Algebra 12+, as a supplement to their regular instruction, will show statistically significant gains in their ability to solve linear equations when compared to those not playing the game.

H.2. Students who engage in game-based simulations (Dragonbox Algebra 12+) will show statistically significant gains in their motivation towards classroom mathematics.

Rationale for Methodology

In order to gather data to address the research questions, this study was performed using both quantitative and qualitative methodologies. Because of the degree of difficulty with maintaining strict systemic control of the testing environment, a quasi-experimental research design was used. This type of experimental study allows for the lack of full randomization with the separate groups of seventh grade students. Every effort was made to meet the conditions of true experimental design, but with logistics on administrative input and social dynamics there was some variation among the control and treatment groups.

Based on scheduling and recommendations from the previous years' teachers, the population of seventh grade students were broken into two main groups: a compacted group (high meets to exceeds expectations) and a grade-level group that has a mix of well-below to approaching grade-level expectations according to Common Core State Standards (CCSS) and Smarter Balanced Mathematics Assessments (SBAC) test results. These groups were further divided to accommodate for class size into subgroups of two compacted groups (39 students total), and two grade level groups (47 students total). The entire population of students ($N = 86$) is broken into four classes for their math periods. Both of the grade-level classes have a range from approaching to meets, with an attempt to make each group equal in numbers, boy/girl ratio, and academic progress. In the grade-level population there are 13 students that are on Individual Education Plans, three students on 504 plans, three students identified as Talented and Gifted (TAG), and one student identified as English Language Learner (ELL). In the compacted math group, there are 17 students identified as TAG, and none of the students receive special services due to ELL, 504, or IEP.

In this mixed methods quasi-experimental study, the hypotheses about the possible causal effects of the independent variable (Dragonbox Algebra 12+) on three separate dependent variables will be tested. The dependent variables that will be addressed are: procedural knowledge (simplification and solving algorithms), conceptual knowledge (applying algebraic understanding to determine solutions to more complex problems), and level of motivation (towards mathematics and TEL supplements). In order to address H.1, a pretest/posttest design will be used to gather data on ability to solve linear equations (both single and multiple step) before the implementation of the intervention and then again after the treatment period. To address H.2 an additional part of the study will focus on the gathering data on the impact of the independent variable (DGBL) on level of a student's continued mathematical motivation with a pretest/posttest design.

Participants and Setting

SES School is a K-8 institution in the Pacific Northwest. It is a neighborhood school that serves approximately 575 students and uses a thematic place-based environmental curriculum. According to the principal's message to the community, SES School is:

> a school where students are empowered agents of change who recognize the existing
>
> connections between people, places, and power, and are dedicated to transforming their
>
> communities through social action that improves the lives of all. Our school uses anti-
>
> racist, place-based, and experiential pedagogy and curricula to explore and critique the
>
> complex connections within and between communities. Together students and teachers,
>
> in partnership with parents and community members, study how physical places intersect
>
> with the stories and power hierarchies of the people who are connected to these places,
>
> with the purpose of developing a strong sense of civic responsibility and stewardship,

responding to inequitable conditions that affect our communities, and practicing tools that

challenge the dominant paradigm. (OregonReportCard, 2017)

SES school administers annual standardized assessments in the Spring, while there are

district windows for administering benchmark assessments. The seven middle school classes are

not required to administer benchmark testing quarterly; and at the start of the study, these results

were not available from the previous year. The results of the 2015-16 Smarter Balance

Assessment Consortium (SBAC) report that 62% of students that participated in the assessments

(3rd-8th) are meeting the accountability benchmark in mathematics compared with 59% in 2014-

15 (OregonReportCard, 2017). The average percentage of students meeting the math

benchmarks of SES is above the 44% Oregon state performance average (OregonReportCard,

2017). Based on the lack of availability of the test data, it was not possible to obtain a

benchmark measure of the students who would be participating in the study.

The district's guidelines for the mathematics curriculum for 7th grade is in the form of a

recommended pacing for each learning target are were created by a team of teachers to assist

with content alignment to Common Core State Standards in mathematics, goal setting, and

student communication. The curriculum resources used by SES middle school math program are

from the Connected Mathematics Project developed by Michigan State University and funded by

the National Science Foundation (Michigan State University, 2018). This inquiry-based,

problem-centered approach is utilized in the math classes, while the creation of a new STEM

class will be offered to the 7th grade students to supplement their curriculum.

Due to the large size of the 7th grade class, the population has been divided into four sub-

sections (two compacted classes, and two grade-level classes). Each of the four classes will have

a close to equal number of students (between 20 and 23), with a total of 87 participating students

in the study, which will represent 100% of the seventh grade students at the middle school. The

ethnic makeup of the school is about 79% White, 11% Multi-racial, 6% Latino/Hispanic, 2%

Asian, 1% American Indian/Native Alaskan, and 1% Black/African-American. Of the total

population, 27% are classified as economically disadvantaged. These numbers differ based on

the database accessed due to updated information that the school has received since the start of

the study. A breakdown of the students in each of the two main groups is depicted in Table 1.

Table 1

Numbers of Students in Descriptive Categories Based on Math Placement, Gender, and Ethnicity

	Control	Treatment
Compacted Math Total	*n* = 20	*n* =19
Female	12	11
Two or More	3	2
White	9	9
Male	8	8
Asian	0	1
Hispanic	1	0
Two or More	1	0
White	6	7
Grade-Level Math Total	*n*=22	*n*=25
Female	14	9
Asian	1	1
Hispanic	2	1
Two or More	2	3
White	9	4
Male	8	16
American Indian/ Alaskan Native	0	1
Asian	1	1
Black/African American	0	2
Hispanic	1	0
Two or More	1	2
White	5	10

Students participating in the study have been assigned into the compacted or grade-level mathematics groups based on results from the previous year SBAC scores and by teacher recommendation. These two subgroups of the entire 7th grade population strengthened the research design and controlled for the extraneous variables of gender, socioeconomic status, and ethnicity. The groups were a convenience sample; they were intact based on who was enrolled in the seventh grade at the school. Each of these groups will be divided into two subgroups to serve the purpose of comparison groups in the study. Potential significant group differences (e.g., history, maturation, testing) can alter the results of the research and understanding the difference of the groups in the pre-test can account for these types of threats to the study's internal validity. The control group will receive traditional math instruction with two different supplementary non-gaming digital activities: Khan Academy and Desmos Graphing Calculator. The treatment group will receive traditional math instruction with a supplementary DGBL component: Dragonbox Algebra 12+. Both groups will have a total of 120 minutes of digital intervention during the STEM class time over the 14-day period.

Game Selection: Dragonbox Algebra 12+

Current DGBL software development targeted at middle school students, specifically with the focus of algebra, is sparse. Game design for educational software is marketed towards a younger audience and employ a practice set design. Many of the popular titles are non-game based but utilize elements of fantasy and gaming, mostly in the form of esthetics. When considering available educational games to work with, the goal was to use a DGBL platform that had the necessary characteristics that support learning outcomes and motivation and also was limited in the requirements for previous knowledge of algebraic expressions and equations. A

learning model proposed by research in the field of instructional games takes into account

attributes of the game in conjunction with instructional content, the game cycle that the user is

engaged in, leading achievement of objectives and specific learning outcomes (Garris, Ahlers,

Driskell, 2002). The *System Feedback* component of the process is oftentimes where the

embedded scaffolds can be found to impact motivation of the player, and to guide the learning

process (Garris et al., 2002; Kron, Falstein, & Marcella, 2013). *Figure* 1 demonstrates the model

that was used to help select the game for this project.

Figure 1

Input-Process-Outcome Game Model
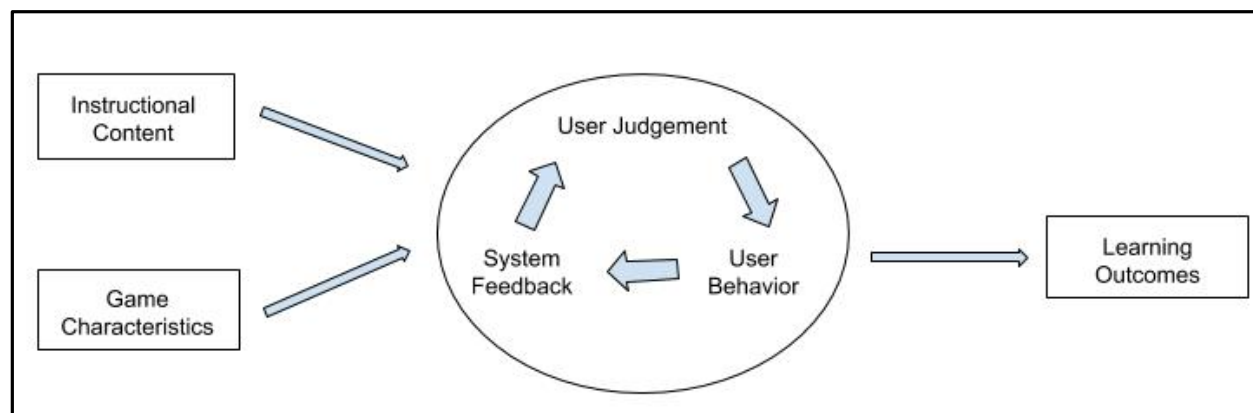
Note: Reprinted from Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: A research and practice model. *Simulation & Gaming, 33*(4), 441-467.

The Dragonbox software series of math games was developed by the Oslo-based software

developer WeWantToKnow, in 2012. The series includes games that vary in difficulty and

targeted age ranges. Dragonbox Algebra 5+ takes the player through 10 chapters of gameplay,

and introduces basic algebraic concepts geared towards a younger audience (ages 5-8).

Dragonbox Algebra 12+ (Figure 2) builds a deeper understanding of how to manipulate algebraic

equations with single and multiple steps, and advances the user towards integers and inverse

operations with rational numbers. Rather than a game that takes players through a series of

repeated patterns with classic algebra symbols, much like an electronic worksheet, Dragonbox

Algebra 12+ employs basic pattern recognition through representative images/symbols.

Utilizing symbols, the player will work through numerical properties in a game-based format,

including: Additive Identity, Additive and Multiplicative Inverse, Equality and Negation,

Distributive, Factoring, Associative, and Commutative properties.

Figure 2

Dragonbox Algebra 12+ Screenshot
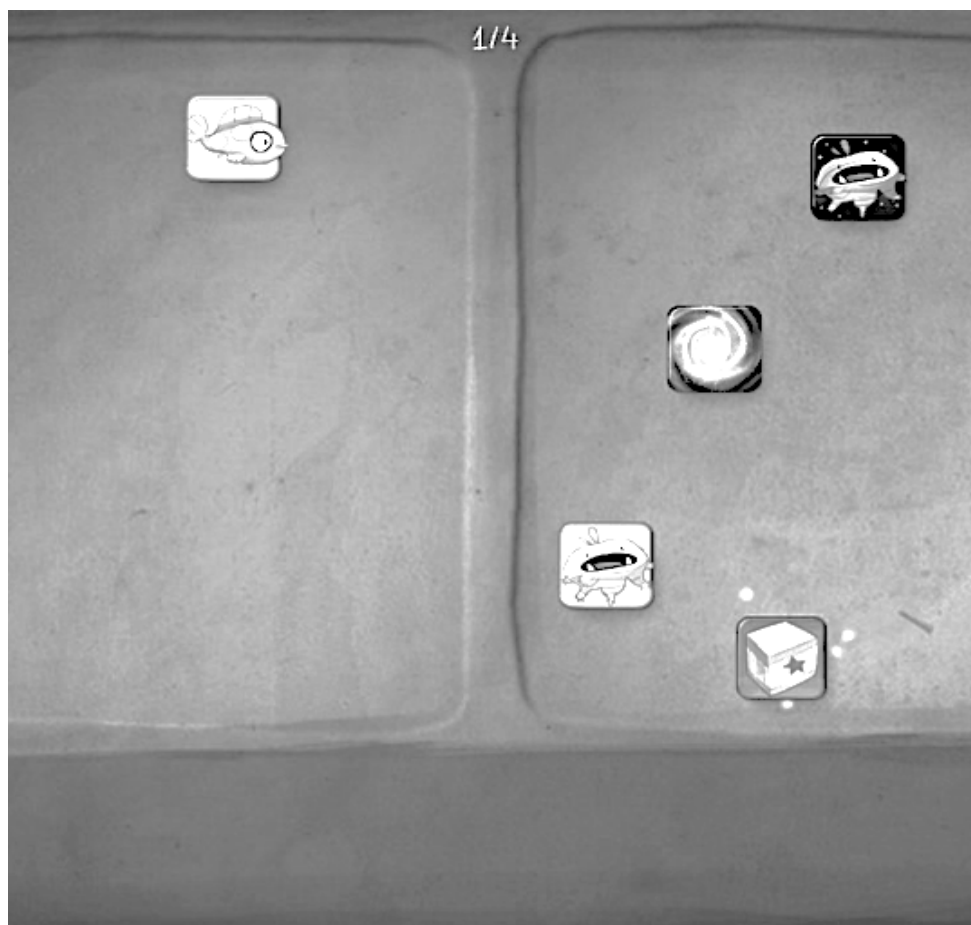
One of the initial attractive features of the Dragonbox Algebra 12+ game was the use of

iconic representations to help students move from concrete to more abstract thought. While

many DGBL capitalize on the use of procedural knowledge to provide repetitive problem sets,

they seem redundant in much of the practice that is done in the classroom. For example, a math

routine might include the introduction of the procedures to solve a single-step algebraic

expression to determine the value of the unknown variable, and then require the students to do

several paper-based practice problems. In an attempt to implement technology into the

curriculum, easily accessible online practice set software is often used to supplement the

classroom instruction and practice. Oftentimes this turns the computer-based tasks into a series

of electronic practice sets, that follow the paper-based sets. An alternative method to the practice

sets is software that requires the user to problem solve in a gaming platform, and not make it

seem as if the student is being given more problems to solve. Interactive design model methods

using iconic (pictures) representations are at the beginning stages of development and have

potential to increase a student's understanding of math and to enhance skills to make connections

in mathematics (National Council of Teachers of Mathematics, 2000).

Using the learning model as a framework, the deliberate choice to use Dragonbox

Algebra 12+ was made by the researcher based on the blending of instructional design elements

with constructivist activities, platforms that include variables that target student interest, and

scaffolding measures to ensure student success. Gagne's (1985) work on conditions of learning

can be applied to elements found in the Dragonbox Algebra game: gaining attention, informing

the learner of the objectives, stimulating recall of prior learning, presentation of the content,

providing "learning guidance," prompting opportunities for practice, providing feedback,

assessing performance, and facilitating transfer. Wrapping these principles into a constructivist

framework, it is not a stretch to see how the opportunities to practice and perform in a defined

space leaves room for learners to explore and actively process to construct meaning. The

Dragonbox Algebra 12+ software has design elements that promote student involvement

specifically within a DGBL environment: (a) rules, (b) clear but challenging goals, (c) a fantasy

scenario linked to student activity, (d) progressive difficulty levels, (e) interaction and high degree of student autonomy, (f) uncertain outcomes, (g) immediate feedback (Papastergiou, 2009).

The final feature that was appealing about the Dragonbox game was the embedded scaffolding measures that promote mastery goals. Scaffolding measures that encourage short-term goals can be found within the game as part of the point system based on the number of manipulations that can be used to solve each equation. These points then equate to the type of avatar that the student is creating: the more points earned (less moves made) the more powerful the avatar will become. Strategies that provide and promote feedback within the game are guides that help the student know if they are solving a problem correctly (by using colors) and what variables they have to eliminate (animation).

Procedures

Following the district's curriculum pacing guide, there are 14 days allotted for the study of linear equations for 7th grade in early fall. The dosage for the study was consistent with the duration outlined on the district calendar; this constraint will be addressed in the limitations section.

Regular math instruction at SES takes place four days each week (Monday, Tuesday, Wednesday, and Friday) for a duration of 55 minutes per day. The model used by SES school is similar to double-dose of math classes each day: one period of traditional math class (lecture-based format), and one 55-minute period of applied mathematics through a STEM-based curriculum. While the students attend their regular math class each day (4 days/week), they cycle through the STEM course in two-week blocks. For the purpose of this study, the DGBL portion of the research will be assigned to two of the four periods each week; each session will

last 30 minutes, for a total of 240 DGBL minutes (120 minutes per treatment and control group) in a 14-day period. Due to a fluctuating calendar, it is difficult for the days of the week that DGBL will be implemented to remain consistent throughout the study (see Limitations), but all attempts were made to plan for and maintain Tuesday and Friday as the DGBL component.

During the days in which computer supplemented instruction is scheduled to be used, there will be an instructional and guided-practice format with the students in both treatment and control groups. Prior to the initial class session in which the supplementary digital activities are implemented, students will be introduced to instruction on accessing the programs, login procedures, saving progress, and reporting results (done through the individual digital media software).

On the intervention days, the initial portion of the class will be used for addressing the project work and clarifying procedural pieces in the context of the problem-based work. The second portion of the period will be maintained for DGBL: Dragonbox Algebra 12+ for the treatment group and non-gaming digital programs for the control group. Two different non-gaming programs have been chosen for the control group to work on during the course of this study. Khan Academy was primarily chosen as the technology supplement based on the familiarity with the program from the students' sixth grade math classes and for its popularity in math programs throughout the nation (Keene, 2013). Desmos was chosen to be used in addition to Khan Academy to provide non-gaming activities used in conjunction with a built-in HTML5 graphing calculator. Both the Khan Academy and Desmos supplements are free to use and provide a login through the students Google accounts (provided by the school district). Students working in the treatment group will continue their progress from session to session, while the

control group will work through activities assigned to them by the teacher-researcher that coincide with current in-class material.

During the classes when there will not be a DGBL component, all students will be working on projects that involve real-life applications of linear equations in a variety of formats. There will be independent work and small group work on conceptual problems involving their procedural knowledge. A problem-based unit has been developed by the researcher as part of the daily coursework and serves to make connections between real-life applications of linear equations and the topic of navigation. For the initial half of the period, learning targets will be addressed and scenario-based problems will be introduced and worked on either independently or collaboratively for the remainder of the period. For the purposes of the study, explicit instruction on the procedural components of solving single-step and multi-step equations will be limited to solutions within the context of the unit problems. Based on the findings of current research on classroom instruction methods that positively impact procedural and conceptual knowledge (Ross & Wilson, 2012), the participants will receive meaningful feedback on their daily work in a timely fashion (within one class period). Feedback includes scored assignments and teacher comments (both written and verbal).

Before the intervention procedure began, all participants were tested for motivational and skill levels. After the intervention, all participants were again tested with the same two instruments (described below).

Instrument Selection and Analyses

Two measurements were used to gather quantitative data: algebra pretest/posttest, and the Student Motivation Survey. Cronbach's alpha reliability coefficient was confirmed at both pre-

and post- for both of the measures ($\alpha > .80$). Pre- and post- assessments were identical and were used to compare the students' mean scores before and after the intervention.

The procedural algebra pretests and posttests (Appendix B) were created by the researcher with individual items compiled from McGraw-Hill (2002) Pre-Algebra workbook. The selected items were chosen based upon research done by Ross (2006, 2010) on middle school students' algebraic understanding, specifically to investigate procedural and conceptual knowledge on problems that involve linear equations. The tests were comprised of multiple choice, short response, and word problem type questions. The procedural component was assessed with ten items, composed of two multiple choice questions and five short response questions, and 3 extended response word problems. This section was used to test the relation of algorithmic and rote knowledge of algebraic ideas. The test was determined to have content validity based on a panel of experts (three college faculty with backgrounds in mathematics education).

Conceptual understanding was assessed with a separate measure that contained two extended response items. The questions assessing conceptual understanding involved an expanded opportunity for students to make connections and applications using a thorough understanding of underlying mathematical concepts. The questions used to assess conceptual knowledge involved an opportunity for students to make connections and apply their procedural understanding to real-world situations. The 6th through 8th grade algebra strand expects students to "represent, analyze, and generalize a variety of patterns with tables, graphs, words, and symbolic rules," and to "identify functions as linear or nonlinear and contrast their properties from tables, graphs, or equations." (National Council of Teachers of Mathematics, 2000, p.395). Maintaining relevance to the concepts targeted as part of the unit, it was not possible to pretest

the subjects, as they would not have been exposed to enough of the content to make it worthwhile. Written responses to the questions were coded according to the level of correctness using 0 for incorrect, 1 for partially correct, and 2 correct. The level of correctness for open-ended questions was recorded based on Ross' (2006) work with determining growth in procedural and conceptual knowledge. The same panel of experts determined the content validity of this measure.

Originally, a non-mathematics colleague agreed to distribute the test to the students during her class time. However, this did not materialize, as the colleague changed her mind due to her own instructional time constraints. Therefore, a convenience sample of the total population was used to assign the test to both the control and treatment groups. Due to the factors of time constraints and student availability the decision was made to administer the assessment to a convenience sample, which represents 59 percent of the entire 7th grade population.

The algebra pretests and posttests were scored by the teacher-researcher. Multiple choice items were coded as 2 for correct, 1 for incorrect with evidence of work shown (due to the multi-step nature of the problems), and 0 for incorrect. Written responses were coded according to the level of correctness using 0 for incorrect, 1 for partially correct, and 2 for correct.

In order to measure the motivation for continued learning in mathematics, two types of data were collected. First, a Student Motivation Survey (SMS) created by Abdelhafez (2016) was used. The SMS is intended to be a situational measure of students' perceived levels of motivation toward a course. This instrument is based on Keller's (1987) ARCS Model which defines four major conditions of motivation: attention, relevance, confidence, and satisfaction. The SMS was used to measure participants' motivation at the beginning and completion of the 14-day period of intervention. The instrument uses a 5 point Likert-type scale. Each item was

scored from one to five points, depending on the favorableness of the response. Therefore, the possible minimum score on the 20-item survey is 20, and the possible maximum score is 100. The teacher-researcher compared the total score on the motivation instrument before and after the intervention using an analysis of covariance (ANCOVA). Split-half reliability to validate the measure was calculated by Cronbach's alpha, and confirmed that there was good internal consistency ($\alpha = .865$). In order to address potential issues of internal validity pertaining to the instrumentation, the teacher-researcher had an independent third party (middle school teacher) administer the SMS. Due to a small group of students that did not complete the survey in its entirety, an average imputation method was used to determine missing values of the items. This will be discussed further in the Limitations section.

Changes in student mathematics achievement and motivation were determined by the use of ANCOVAs (run through SPSS) to account for pretest scores while comparing the posttest scores between treatment and control groups. Descriptive statistics measured procedural and conceptual gains and standard deviations revealed the distances that scores were from the mean in order to observe the differences and similarities between performances on procedural type questions as compared to conceptual type questions. In terms of academic performance and motivation, the mean gains revealed high or low scores which could be examined further and become part of purposeful sampling for the interview research. The use of ANCOVA tests also helped to determine whether the use of a covariate (compact or grade-level math group) can increase the ability to detect differences between the groups (treatment or control), and provide additional information on how the leveled groups were impacted.

A post-study questionnaire was created by the researcher and administered to the entire population of students via a digital form through Google Forms. There were Likert scaled

questions (on a 5-point scale) to target a student's level of motivation by questioning elements of situational interest and their perception of how their problem solving skills changed over the course of the DGBL portion of the study. The final item on the form contained an open-ended follow-up response to the question, "Compared to other lessons, how much math do you think that you learned by using interactive simulations?", that asked students to explain and provide an example of their answer. Data analysis for the qualitative portion of the research included a preparation of the transcripts for further study by assigning codes that can be further reduced to themes by a three-cycle coding method. Interpretation of the data serves to help create a story to triangulate with the quantitative measurements.

The following questionnaire items were created based on questions used in research studies on the field of situational interest (Linnenbrink-Garcia et al, 2010; Mitchell, 1993) and motivation (Hidi & Harackiewicz, 2000).

The protocol for the questions is as follows:

1) **Indicate how much you agree or disagree with the following statement: "I looked forward to the days that we used computers as part of the STEM class."**

2) **How would you rate your experience with the Dragonbox/Khan Academy/Desmos activities?**

3) **Compared to other lessons, how much math do you think that you learned by using interactive simulations?**

4) **Indicate how much you agree or disagree with the following statement: "Video games and computer simulations help me to learn."**

Ethical Considerations

There are important ethical issues while conducting classroom studies because this approach to educational research typically involves an intervention and/or extended contact with children. In addition to adhering to IRB considerations, the researcher made all necessary attempts to ensure that fair and appropriate education is not being withheld from students, and the treatment and control groups both received adequate instruction, supplemental materials, and access to additional help. The IRB granted permission to conduct this research study on November, 2, 2017.

Role of the Researcher

The teacher-researcher has 14 years of classroom teaching experience in the public and private settings in Hawaii and Oregon. Experience as a licensed educator began in 2006, while specifically working within an intermediate math program began in 2008 in Hawaii. A relocation to Oregon in 2011 allowed for a transition into 6th-8th grades in a private institution in the Portland area (2011-2016), Algebra level credit recovery courses at a public high school in Portland (2017), and currently at SES (2016-present).

For this research, quantitative data will be gathered by the teacher-researcher using a quasi-experimental approach. In the current study, the quantitative data was comprised of multiple measures. Although quantitative research is scientific in nature, in this study, the researcher will be an integral part of the research process. As part of the sequential explanatory design, qualitative data will be gathered in a second phase of the study and thematic coding of the data will be performed for a more robust analysis. Neither quantitative nor qualitative methods are sufficient to stand alone to fully capture the trends and details of this study. The goal of the researcher will be to gather data in a non-biased format, deliver instruction on

applications of linear expressions and equations through a project-based unit, and analyze data. There will be no additional instruction to guide the transfer of learning from the DGBL platform to classroom mathematics. While research in the field of DGBL emphasizes it's importance as an external scaffold, it would interfere with the ability to determine growth based solely on game-play and is outside the scope of this study. As an educator of middle school students in a math environment for over 14 years, there are natural feelings about the use of technology that will have to be put aside to allow for naturalistic generalizations to materialize. It is the intention of this researcher to maintain an emphasis on delivering an understanding that represents a complete and objective picture of DGBL in the classroom.

Summary

The study will determine whether students are impacted by the use of DGBL on their procedural and conceptual understanding of algebra items involving one step and multi-step linear equations. The study will also determine if there is an impact on various elements of interest and self-perception that lead to motivation towards classroom mathematics based on quantitative and qualitative measures. Both quantitative and qualitative measure will be used to address the research questions.

Chapter Four: Results

Overview

The purpose of this chapter is to provide the results of the data collection and analysis of the study. The advantage of the quasi-experimental design was the practicality and suitability for the real-world natural setting in the classroom environment. In Chapter 5, limitations of this type of study will be discussed in regards to extraneous variables influencing dependent variables. The quantitative and qualitative data collected in this study were used to determine the effects of digital game-based learning (DGBL) on 7th grade students' procedural and conceptual understanding of linear equations and the impact of the DGBL on their motivation towards mathematics. The independent variable, DGBL, is defined as the supplemental use of digital games and exercises in the learning environment during Science, Technology, Engineering, and Mathematics (STEM) class. The dependent variables, procedural and conceptual math achievement and motivation, will be defined by independent measures before and after the intervention period.

The research questions guiding the study are: (a) how does digital game-based learning impact procedural and conceptual mathematical understanding among students? and (b) how does digital game-based learning affect learners' motivation towards classroom mathematics? The corresponding null hypotheses were the following: (a) there will be no statistically significant difference in procedural or conceptual understanding of linear equations, as measured by a researcher-created Algebra assessment, between students who used the DGBL platform with traditional math methods versus students who used practice set digital learning and traditional math methods; and (b) there will be no statistically significant difference in levels of student motivation as measured by the Student Motivation Survey (Abdelhafez, 2016) and the

researcher created post-study questionnaire. The following items were used by the researcher to determine change in mathematical understanding and motivation:

1. Researcher-created pretest/posttest mathematics measure (see Appendix B)

2. Student Motivation Survey (see Appendix A)

3. Conceptual mathematics measure (see Appendix C)

4. Separate post-study questionnaires on motivation and perceived learning for treatment and control groups (see Appendices D & E)

This chapter will provide the quantitative and qualitative results of assessments used throughout the course of the study, with an analysis of the data as they specifically relate to the research questions.

Quantitative Data Analysis

An algebra assessment was administered prior to commencing the unit to determine the students' baseline procedural understanding of single-step and multi-step linear equations. Although only the treatment group received the DGBL supplement, all students received the same instruction and project work relating to applications of linear equations to real-world problems and scenarios. The types of questions on this test were open-ended (8 items) and multiple choice (2 items). The identical algebra pretests and posttests were scored by the teacher-researcher. Items (#1-8) were coded according to the level of correctness using 0 for incorrect, 1 for partially correct, and 2 for correct. The multiple choice items (#9 and #10) were scored 0 for incorrect, and 1 for correct. There were two answers to question #10, and in order to receive credit for this answer, both answers needed to be indicated. A maximum score on the assessment would be 18, while the lowest possible score would be 0.

The Student Motivation Survey (SMS) was used to assess the level of motivation toward mathematics at the beginning and at the end of a 14-day intervention period. The SMS was scored on a 5 point-scale, with a possible range of 20-100; the lower the score, the higher the degree of motivation. Both the SMS and the procedural algebra test was administered a second time at the completion of the unit.

Algebra assessment. Initially, descriptive statistics were conducted on scores for the math pre-assessment to determine differences in the treatment and control groups and provide a summarization of the entire population, while also considering the additional factor of the math class assigned to (grade-level or compacted). As shown in Table 2, there were 40 students in the treatment group and 37 students in the control group. The number of students varies from the reported sample numbers in Table 1 (Control $n = 42$; Treatment $n = 44$) due to missing data; students were included if they had completed both the pretest and the posttest. An independent samples t-test confirmed that the observed difference between the group means was not significant at the pre-test t(76) = 1.476, $p = .144$. Table 2 shows descriptive statistics in regards to a student's placement into the general grade-level classes compared with students in compacted math classes. There were 42 students assigned to the grade-level math class (22 represented in the treatment population) and 35 students in the compacted math class (18 represented in the treatment population). The students in the compacted class scored considerably higher in the math pre-assessment ($M = 11.4$, $SD = 3.35$) than the students in the grade-level class ($M = 4.29$, $SD = 2.64$). Due to the factor of math placement as a strong indicator of performance as evidenced by the large discrepancies in the mean scores both pre and post), and a proportionate representation of both grade-level and compacted students in treatment

and control groups, the determination was made to continue the data analysis for the study without disaggregating for math placement.

Table 2

Descriptive Statistics of Pre/Post Math Assessment by Group and Math Placement

	Pretest		Post-test	
	Mean	*SD*	Mean	*SD*
Control (*n* = 37)	8.32	4.58	11.14	5.16
Grade-Level	5.10	2.53	7.40	3.53
Compacted	12.12	3.37	15.53	2.67
Treatment (*n* = 40)	6.78	4.62	10.45	4.77
Grade-Level	3.55	2.58	6.95	2.75
Compacted	10.72	3.29	14.72	2.76
Total (*N* = 77)	7.51	4.64	10.78	4.94
Grade- Level	4.29	2.64	7.17	3.12
Compacted	11.40	3.35	15.11	2.71

Table 3 presents the mean and SD values in addition to changes from pre- to post-mathematics assessment scores for individual test items. An item by item analysis was completed to determine if there would be differences from pre to post based on individual questions. An Analysis of Covariance (ANCOVA) was run to determine the effect of the interventions of DGBL on the math performance of the treatment group compared with the control group, while also allowing the equalization of initial differences between the groups. The

results of a paired samples t-test confirmed that there was a statistically significant mean difference between the pre- and post-tests for the entire population of students $t(76) = 9.775, p <$ .05, there was an average gain in mean score of 3.26 points. Mean scores at pretest were found to be slightly higher in the control group ($M = 8.32, SD = 4.58$), as compared with the treatment group ($M = 6.78, SD = 4.62$), with an overall average gain in mean of 2.82 points for students in the control group and 3.67 points in the treatment group. The variation in the measure of standard deviation was similar in both the experimental and control groups. Although both groups made gains from the pre- to posttest, after adjustment for pretest scores, there was not a statistically significant difference in the experimental intervention group compared with the control group ($F = 1.036, p = .312$). Although the results of the statistical tests did not indicate a significant difference in the results, the procedural understanding of the 7th grade students increased overall during the course of this study, and in all but three items (#5, #9, and #10), the treatment group made greater gains from pre- to posttest.

Table 3

Mean Scores of Pre- and Post- Mathematics Assessment by Treatment and Control Groups

	Pre		Post		Change from Pre to Post			
	Control (*n* = 37)	Treatment (*n* = 40)	Control (*n* = 37)	Treatment (*n* = 40)	Control	Treatment	*F*	*p* - value
Total	8.32 (4.58)	6.78 (4.62)	11.14 (5.16)	10.45 (4.77)	2.82	3.68	1.036	0.312
1	0.70 (0.85)	0.43 (0.71)	1.05 (0.88)	1.05 (0.81)	0.35	0.62	0.737	0.393
2	1.41 (0.83)	1.13 (0.94)	1.57 (0.77)	1.58 (0.71)	0.16	0.45	0.218	0.642
3	1.60 (0.80)	1.5 (0.88)	1.73 (0.65)	1.75 (0.63)	0.14	0.25	0.118	0.732
4	0.89 (0.97)	0.8 (0.85)	1.27 (0.87)	1.38 (0.77)	0.38	0.58	0.838	0.363
5	0.27 (0.56)	0.23 (0.48)	0.65 (0.75)	0.58 (0.59)	0.38	0.32	0.125	0.724
6	1.08 (0.64)	0.85 (0.66)	1.22 (0.58)	1.2 (0.65)	0.14	0.35	0.405	0.526
7	0.70 (0.57)	0.63 (0.63)	0.86 (0.48)	0.85 (0.53)	0.16	0.22	0.003	0.957
8	0.89 (0.74)	0.75 (0.81)	0.92 (0.68)	0.88 (0.76)	0.03	0.13	0.059	0.808
9	0.54 (0.87)	0.43 (0.78)	1.14 (1.00)	0.75 (0.95)	0.60	0.32	2.639	0.109
10	0.24 (0.49)	0.05 (0.22)	0.73 (0.80)	0.45 (0.64)	0.49	0.40	1.892	0.173

For additional analysis on question types based on the difficulty of the procedural operations, groupings of items were created. The individual items have been categorized into 4 groups within the algebra strand: simplification of linear expressions (S1, S9, and S10), single-step equations (SS2 and SS3), multi-step equations (MS4 and MS5), and algebraic word problems (WP6, WP7, and WP8). Items that are classified as simplification only require the manipulation of the equations; items that involve single-step and multi-step equations require computing with rational numbers, coefficients, and variables in addition to simplification; while items in the category of word problems require translating into algebraic expressions and equations, performing calculations, and then simplifying. For the purposes of looking at the data, simplification items would be classified as a superficial procedural task, followed in difficulty by the single-step and multi-step problems, and finally increasing in difficulty to the word problems as an example of deeper procedural understanding (Star, 2005). Table 4 shows the subcategories of procedural knowledge in the algebra strand that covers linear equations from the pre- and post-assessment. Consistent with findings in Table 2, there was growth with both groups in each of the four domains. The treatment group demonstrated larger gains in mean score in solving single-step ($M_{change} = 0.35$) and multi-step linear equations ($M_{change} = 0.46$), and their ability to solve word problems ($M_{change} = 0.32$). Although both the treatment and control groups made gains from pretest to posttest in the problem types (simplifying, single-step equations, multi-step equations, and word problems), the differences were not statistically significant (refer to p-values in Table 2).

Table 4

Descriptive Statistics by Item Type of the Pre-/Post- Math Assessment

	Control N = 37		Treatment N = 40		Change from pre to post	
					Control	Treatment
	Pre	Post	Pre	Post		
Simplifying	0.49	0.97	0.30	0.75	0.48	0.45
S1	0.70 (0.85)	1.05 (0.88)	0.43 (0.71)	1.05 (0.81)		
S9	0.54 (0.87)	0.14 (1.00)	0.43 (0.78)	0.75 (0.95)		
S10	0.24 (0.49)	0.73 (0.80)	0.05 (0.22)	0.45 (0.64)		
Single-Step Equations	1.51	1.65	1.32	1.67	0.13	0.35
SS2	1.41 (0.83)	1.57 (0.77)	1.13 (0.94)	1.58 (0.71)		
SS3	1.60 (0.80)	1.73 (0.65)	1.50 (0.88)	1.75 (0.63)		
Multi-Step Equations	0.58	0.96	0.52	0.98	0.38	0.46
MS4	0.89 (0.97)	1.27 (0.87)	0.80 (0.85)	1.38 (0.77)		
MS5	0.27 (0.56)	0.65 (0.75)	0.23 (0.48)	0.58 (0.59)		
Word Problems	0.89	0.94	0.51	0.83	0.05	0.32
WP6	1.08 (0.64)	1.22 (0.58)	0.85 (0.66)	1.20 (0.65)		
WP7	0.70 (0.57)	0.86 (0.48)	0.63 (0.63)	0.85 (0.53)		
WP8	0.89 (0.74)	0.73 (0.80)	0.05 (0.22)	0.45 (0.64)		

Motivation assessment. In order to determine change in motivation towards mathematics, the Student Motivation Survey (SMS) was administered before the 14-day intervention period, and then immediately following. The discrepancy in sample size from the data presented in Table 5, compared with the population size is due to missing data (either a missing pre or post survey). Only students that had completed both the pre-survey and the post-survey were included in the data sets (Control $n = 35$; Treatment $n = 37$). An independent samples t-test revealed that there were no significant differences at pre-test ($p > .05$), with a total mean difference of 2.06 points. Table 5 presents the findings of the results of the ANCOVA in the table indicated no significant differences on the motivation of the control group versus the treatment group in any single item or in total scores. Both of the groups demonstrated an increase in scores according to the SMS, but the difference was not statistically significant ($F = .606$, $p = .439$). This suggests that students' motivation toward mathematics class actually lessened over the course of the study for both the treatment and control groups. Overall results were determined by a paired samples t-test which did not find that the motivation scores differed significantly from pre- to post- measures $t(71) = .971$, $p > .05$, with a mean difference of .942 points. In determining the scoring of this measure, values that increased showed a negative change in motivation, while scores that decreased would demonstrate a positive change in motivation.

Table 5

ANCOVA and t-test Results of the Student Motivation Survey

	Pre		Post		Change from Pre to Post			
	Control (*n* = 35)	Treatment (*n* = 37)	Control (*n* = 35)	Treatment (*n* = 37)	Control	Treatment	*F*	*p* - value
Total	51.8 (11.7)	53.9 (9.4)	54.0 (12.2)	54.2 (10.7)	2.2	0.3	.606	.439

Conceptual assessment. In order to determine conceptual understanding differences between the groups, a 2-item post-test (Appendix C) was administered that related to the problem-based unit the students had been working on for the duration of the study. The two-item assessment centered on using a mathematical model to represent and analyze real-world scenarios. Written responses were coded according to the level of correctness using 0 for incorrect, 1 for partially correct, and 2 for correct. A maximum score for the 2-item measure would be 4, while the lowest possible score would be 0. Ross (2006) demonstrates the use of conceptual items using a 2-point scale for correctness. Items were scored 2 for illustrating and providing a correct answer to the problem. Items that had incorrect solutions but showed evidence of work that contributed to evidence of procedural processing scored one point. Items that had a response of blank, "I don't know", or unrelated work received a zero. Item 1 on the assessment tasked the students with applying an ordered pair to determine if it was a solution to a linear path of travel (single-step linear equation task). The second item had the students substitute a value to evaluate for an unknown coordinate in a system (multi-step linear equation task). Both of the assessment items were based on the navigation concept that the students had been exploring as part of the 14-day unit. It was determined that this tool would be an

appropriate measure of conceptual understanding based as the panel of experts aforementioned

determined that the items satisfied the requirements based on Hiebert and Lefevre's (1986)

definition of conceptual understanding. Table 6 shows the average number of points according

to the item number and point value. The overall scores ranged from 0 to 4 points, with the

treatment group outperforming the control group on total mean scores by 0.16 points. Results of

the ANOVA showed that there were no significant differences between the groups, $F_{(1, 48)} = .140$,

$p > .05$. A chi square test was performed to determine if there was an equal distribution of

respondents among the population when taking into account the mathematics class assigned to

(grade-level or compacted), as evidenced by Table 7. The results of the observed frequencies of

the variables was not significant using a one-tailed goodness-of-fit test $X^2(1, N = 50) = 2.053, p >$

.05. Students did fairly well, with over 60% scoring a 3 or 4 in both groups.

Table 6

Mean, Standard Deviation, and Percentages of Scores on the Conceptual Assessment

		Control ($n = 25$)	Treatment ($n = 25$)
	Total	2.64 (1.66)	2.8 (1.35)
Overall Score	0	20%	4%
	1	8%	24%
	2	12%	4%
	3	8%	24%
	4	52%	44%

Totals results are reported in Mean(SD)

Table 7

Distribution of Respondents into Treatment and Control Groups for Conceptual Measure

	Group		*n*
	Treatment	Control	
Grade- Level	8	13	21
Compacted	17	12	29

Post-intervention questionnaire. In addition to the post Student Motivation Survey, a second measure was used at the completion of the study that would serve to determine change in individual satisfaction during the course of the intervention period. A digital questionnaire was administered to all students as a means to gather data on student perceptions of the impact of the digital game-based platform on their learning and motivation. The Google Form was administered in lieu of focus group interviews due to district-imposed time constraints, and the delays with the IRB approval through Portland Public Schools. IRB approval was granted by PPS on November 2, 2017, several weeks after the completion of the intervention. In an effort to maintain integrity of the study, and to not sacrifice the external validity due to operating outside of the specific time period. It was determined that the student's views should be taken at the time of the study, not at a future date when results may be altered due to maturation. Table 8 shows the mean scores of both groups in response to 5 point Likert-scale items on the digitally administered questionnaire. Scores below 3 indicate weaker levels of satisfaction/agreement with DGBL as a means of supplementing the math curriculum, a score of 3 would indicate "neutral", and scores above 3 would show a trend toward higher satisfaction with a DGBL environment.

The first item (question number 2 on both forms) in the questionnaire asked the students to indicate how much they agreed or disagreed with the following statement: "*I looked forward to the days that we used computers as part of STEM class*". The treatment group response suggests that a majority of the students (86 percent) agreed with the statement ($M = 4.32$, $SD = .77$), in comparison with the neutrality of the control group ($M = 3.49$, $SD = 1.23$). A one-way ANOVA was run to determine if the DGBL intervention impacted the students' enjoyment of the days in which computers would be used as part of STEM class. The results indicate that the group means differed significantly ($F_{(1,81)} = 13.89$, $p < .05$), suggesting that students in the treatment group looked forward to the DGBL intervention more often than the non-gaming students.

The next question on the questionnaire (item number 3 on the treatment group form, and numbers 3 and 4 on the control form) asks students, *"How would you rate your experience with Dragonbox/Khan/Desmos activities"*. The items were listed separately on the control questionnaire to allow students to respond to each of the digital interventions specifically (Khan Academy and Desmos). The average response score for students in the treatment group ($M = 4.16$, $SD = .776$) demonstrates that 81.82 percent of the students rated their experience with the DGBL environment as positive. In order to address the different non-gaming platforms used by the control group, the responses were combined, and the total result was in the neutral range ($M = 3.21$, $SD = .985$). Results of the ANOVA indicate that the two groups differed significantly in terms of their self-reporting of gaming experience, $F_{(1,120)} = 30.536$, $p < .05$.

The third comparison on the questionnaire (item number 4 on the treatment form, and number 5 on the control form) asked the students, "*Compared to other lessons, how much math do you think that you learned by using interactive simulations?*". Students in both groups had

similar responses overall, with those in the treatment group having a slightly higher positive indicator of responding 4 or 5, than the students in the control group. Out of the treatment group 43.18 percent ($M = 3.36$, $SD = 1.059$) of students responded with the answer of "more" or "a lot more" to the question compared to the control group's 41.03 percent ($M = 3.23$, $SD = .959$). An ANOVA was conducted to determine if students' self-perception of their learning from supplemental interactive simulations was different between the groups. The results of the ANOVA indicated that there were no statistically significant differences between the two groups, $F_{(1,81)} = .356$, $p > .05$.

The final item on the questionnaire (item number 5 on the treatment form, and number 6 on the control form) asked for the students to self-reflect on the impact of DGBL on their own knowledge and understanding of mathematics using the statement: "*Indicate how much you agree or disagree with the following statement: "Video games and computer simulations help me to learn"*. The descriptive statistics show that both of the groups had a similar experience when comparing supplemental digital learning with a traditional non-tech math lesson and assessing the amount of their own learning as a result of using the interactive simulation. Although the groups' average response was in the neutral range for both of the items, the treatment group ($M = 3.72$, $SD = 1.075$) had a more positive response to the expectancy of success statement, compared to the control group ($M = 3.76$, $SD = 1.078$). The results of the ANOVA did not show there to be statistically significant differences in the two groups ($F_{(1,79)} = .034$, $p > .05$).

Table 8

Responses to the Post-Study Questionnaire Administered to Treatment and Control Groups

	Mean Score		Percent Indicating "Positive"	
	Treatment ($n = 44$)	Control ($n = 39$)	Treatment	Control
2. I looked forward to the days that we used computers as part of STEM class.	4.32	3.49	86.36	56.41
3. How would you rate your experience with the Dragonbox Algebra game?	4.16	NA	81.82	NA
3c. How would you rate your experience with the Khan Academy activities?	NA	2.82	NA	17.95
4c. How would you rate your experience with the Desmos activities?	NA	3.59	NA	53.85
4/5c. Compared to other lessons, how much math do you think that you learned by using interactive simulations?	3.36	3.23	43.18	41.03
6/7c. Video games and computer simulations help me to learn.	3.76	3.72	54.55	66.67

Items labeled "NA" indicate that the question was not part of the questionnaire, *c* denotes the item was part of the control survey

Qualitative Data Analysis

Written comments about the intervention. Students opinions about the use of Dragonbox Algebra 12+ as supplementary to the math curriculum were investigated by an open-ended response as an extension to the post-study questionnaire item "*Compared to other lessons, how much math do you think that you learned by using interactive simulations?*". The follow-up to the Likert scale question asked the students, "*Based on your answer to the previous question,*

can you explain your answer, and provide an example?". The control group was given a similar

prompt, with language more specific to the computer applications that they were using. In

addition to this item, language samples were also analyzed from the final prompt on the

questionnaire, that was identical for both groups, "*Is there anything else that you would like to*

tell me about using [Khan Academy/Desmos/Dragonbox] to learn math?" While the

questionnaires were administered to both treatment and control groups, and differences were

analyzed for relevancy to the specific supplementary digital software; the qualitative data were

also compiled as a whole to evaluate if DGBL (Dragonbox) and interactive simulations (Khan

Academy and Desmos) was an experience that promoted enjoyment as part of classroom

learning.

The initial open-coding of the responses involved the classification of words from the

transcripts to be developed into categories, based on research methodology in qualitative content

analysis (Elo & Kyngas, 2008; Hsieh & Shannon, 2005). The preliminary readings evidenced

that the broad categories with the transcripts could be broken down into positive experiences

with the game, negative experiences, and neutral experiences. Evidence of positive experiences

used language that did not contradict and maintained a positive experience ("I think I learned a

lot, and I used what I learned and applied it to my math."). Statements of a negative experience

were void of positive comments and were explicit in either dislike of the game or confusion ("I

couldn't make connections from the game to what we were learning," or "it really didn't teach

me math . . . it was just sliding boxes around"). Neutral items may have had elements of positive

and negative language, but the overall theme was that of neutrality or indifference ("It [the game]

did not hurt me, but it did not help me", or "I didn't learn anything I hadn't before"). There were

cases in both groups in which students had both positive and negative comments about the

supplementary DGBL and interactive software. Examples of comments that contained both

positive and negative feedback include, "I learned with Desmos but not with Khan Academy,"

and "it [Dragonbox] was fun but it didn't teach me that much math." These were assigned a

category different than "neutral", to maintain a distinction between indifference and mixed

reviews. In total, there were 9 students that made no comment, therefore the sample sizes vary

from the original numbers reported. Table 9 disaggregates the frequencies of the responses of

the treatment group data into categories based on their overall experience with the DGBL

intervention.

Table 9

Percentages of Responses Based on Overall Experience of Digital Interventions

Perception of DGBL Intervention	Percent Indicating*		
	Treatment	Control	Total
	n = 38	*n* = 34	N = 72
Positive Only	55	41	49
Neutral/Unchanging	16	32	24
Negative Only	11	15	13
Both Positive and Negative	18	12	15

*not all students responded to the question. The percentages reflect only those that responded from *n*

Aside from categorizing students' comments as positive, negative, or neutral, or mixed,

student comments were also categorized into themes. Four themes emerged from the initial

coding that contained elements of positive, negative, and neutral language, and cited descriptors

and phrases that denoted comprehension, enjoyment, learning styles specific to the individual,

and relevancy. The categorical themes were created based on research in the field of motivation

(Ames, 1992; Ames & Archer, 1988; Belland et al, 2013; Hidi & Harackiewicz, 2000; Garris et

al, 2002). The theme *Transfer of Knowledge* was developed based on the work of Genter (1983) and the mapping of relations between objects using analogical comparisons, as well as evaluating learning outcomes (Garris et al, 2002). *Accessibility of Content* was a theme that emerged from the coding and was grounded in work on achievement goals in the classroom, and students' awareness of the strategies that make content accessible and recognizing appropriate of delivery method for their individual learning style, and promoting autonomy (Ames, 1984; Ames & Archer, 1988; Belland et al, 2013). The theme of *Developing Understanding* is based on research in motivational design that highlights the use of scaffolding strategies within learning environments (Belland et al, 2013; Belland et al, 2017). The final theme that emerged, *Interface Characteristics*, and was developed based on the work of Hidi and Harackiewicz (2000) and their findings on individual and situational interest, and specific game dimensions for instructional purposes (Garris et al, 2002). According to the comments made by the students, there were comments that could be classified into multiple categories based on attitude and development of understanding ("When things are fun, it helps me learn, and Dragonbox was really fun!"); transfer of knowledge and developing understanding ("During math class, Mitch or Tara will introduce something or give us a problem, and I know how to solve it because of Dragonbox."); and developing understanding and accessibility of content ("It was a lot easier because I am better with hands on learning", "the visual representation made it [learning math rules] easy for me").

Tables 10 and 11 show raw language data and the thematic categories in which they were classified based on multi-step coding process. In the focused coding stage, care was used to accurately represent open-ended responses into the corresponding categories, with redundancies and contradictions recorded into the most appropriate category to convey the

intended meaning. Positive and negative indicators share features that constitute belonging

within a specified category, and caution was used when making connections and transference to

other statements within the transcripts.

Table 10 breaks down the responses for the treatment group into thematic categories with

use of exemplars of the coded language. Some items are identified as having been repeated

multiple times by different students. As evidenced by the analysis of answers, the students that

reported positive experiences with the implementation of the DGBL platform described it as

being fun, attracted their interest, and provided opportunities to connect their learning back into

the classroom. A majority of the negative responses were based in the transfer of knowledge

category, and described issues relating the supplement back to mathematics. Statements that had

elements of both positive and negative language ("It was hard to apply it to real math, but it was

fun", or "it was informative, but not extremely clear") were counted in frequency as a single

response, but in the coding stage, the language was represented in the corresponding indicators

and categories.

Table 10

Focused Coding Developed Themes for Treatment Group Transcripts

Thematic Category	Positive Indicators	Negative Indicators
Transfer of knowledge	• cancel out numbers and variables • understand negative and positive • apply to math*	• didn't understand how it related to math* • hard to apply to math • couldn't make connections
Accessibility of content	• visual representations • computers* make it easier	• it didn't help me • not for me
Developing understanding	• Learn* • understand	• no idea • didn't learn anything
Interface Characteristics	• Fun • cute creatures	• Just sliding boxes around • just like other games

*> 5 repeated responses

Table 11 which summarizes the control group data uses the identical motivational themes as in the treatment group data, while also categorizing words and statements into the appropriate categories. Many of the positive indicators pertained to the transfer of knowledge, while most of the negative indicators referred to a lack of appropriateness relevant to individual learning style and limited accessibility of content. There were instances of mixed feedback that highlighted positives for one of the interactive activities, while experiencing negative reactions toward the other ("I learned with Desmos, but not with Khan Academy", "Khan Academy wasn't a very good fit for me personally because I'm a super hands-on learner. Desmos had a positive effect on me!"). There was one statement that had elements of neutrality and then targeted Desmos

specifically for a positive response: "Khan is very direct and said what to do and told us to just do it. Desmos said what to do and made the experience more fun". Based on the comparison between groups, the control group had more success with the transfer of knowledge from their interactive activities than did the treatment group who needed to rely more on analogy to make the connections back to mathematics.

Table 11

Focused Coding Developed Themes for Control Group Transcripts

Thematic Category	Positive Indicators	Negative Indicators
Transfer of knowledge	• learned more* about slope • learned more about equations	• waste of time • too much math*
Accessibility of content	• hands on and visual • interactive	• didn't explain • need hands-on
Developing understanding	• multiple examples • learn	• hard to understand* • confusing
Interface Characteristics	• really fun • grabs attention	• very slow • boring

*> 5 repeated responses

Summary of Results

The analysis of pre- and posttest scores of procedural algebra understanding did not support the rejection of the null hypothesis; there was no significant effect of DGBL on procedural understanding of linear algebra as evidenced by the pretest/posttest measure. Although gains were made with the entire population of the study in terms of their abilities to solve for unknown variables in single-step and multi-step equations, determine a solution in the context of a word problem, and simplify algebraic expressions, there was not a significant

difference in achievement between the two groups. The results of ANOVA tests revealed that conceptual algebraic understanding did not appear to have been impacted by the supplementary DGBL within the course of the study.

Quantitative results show that student motivation towards mathematics was not determined to be significantly impacted by DGBL as evidenced by the Student Motivation Survey. The scores for the treatment population did show a shift towards an increase in motivation in 45 percent of the items, compared with the control group at 35 percent of the items. Qualitative results on student motivation provided the opportunity to gather more in-depth responses about the treatment on students' motivation toward classroom mathematics by using the intervention DGBL. Analysis of the responses to the post-study questionnaire administered to both groups indicated that the positive responses towards using the DGBL component as part of class was higher for the treatment group (55 percent) than that of the control group (41 percent). Coded analysis on the individual responses of the treatment group regarding the intervention revealed that there was consensus on several elements of the DGBL environment, and further supported the positive experience and enjoyment of the supplement to the traditional classroom mathematics experience.

In conclusion, this study revealed that although there were gains with the procedural understanding of solving linear equations, they cannot be attributed to a DGBL supplement to instruction. The results revealed that the DGBL did not seem to have an impact on their ability to solve conceptual types of problems. The results also yielded mixed findings in terms of motivation; while quantitative analysis failed to show significance, qualitative analysis yielded a broader picture in terms of thematic impact. Chapter 5 will discuss these findings and limitations, implications of the study, and future research needs.

Chapter Five: Discussion and Implications

Discussion of Findings

The quantitative and qualitative findings from this study revealed interesting aspects concerning the implementation of digital game-based learning (DGBL) in the mathematics classroom. A mixed-methods approach was used to gather data in order to address the research questions. Four instruments were used to gather quantitative data: (1) Student Motivation Survey (SMS), (2) the procedural algebra assessment, (3) the conceptual algebra assessment, and (4) post-intervention questionnaire. The SMS was used to determine the amount of motivation towards mathematics that students had prior to the start of the study, and then at the completion of the 14-day period. The procedural math assessment was used to determine a baseline level of knowledge on single-step and multiple-step linear equations, ability to simplify algebraic expressions, and application to contextual word problems. At the completion of the unit, the assessment was given a second time to determine growth in the area of procedural problem solving abilities of linear equations. The conceptual math assessment was used to verify the conceptual understanding that pertained to the problem-based unit that the students had been working on, including the ability to apply their procedural knowledge of algorithms to use in the solutions. The Likert-scale responses on the post-study questionnaire were used to determine students' self-perceptions in terms of motivation and engagement, and impact to learning that the DGBL and non-gaming interventions attributed to. Parametric tests were used to determine any significant changes over time for the scores in each instrument, while frequency and median stats were used to analyze survey data.

Mixed data types were gathered by administering a questionnaire to the students at the completion of the unit. The questionnaire was analyzed in two parts: (1) quantitatively for the

ordinal Likert-scale items, and (2) open-ended responses that provided detailed information about their learning and how the digital technology influenced, or failed to influence it. Analyzing textual content was done by open-coding methods to develop categories based on properties and dimensions related to self-perception of learning and motivation. These categories were used to assist in the sorting and extraction of relevant qualitative findings, and to determine what features of the digital interventions were most effective.

Throughout the study, quantitative and qualitative datasets carried equal weight, priority, and consideration. The results of the quantitative and qualitative analysis were compared and integrated with sensitivity concerning the range of findings. The analysis of data provided empirical evidence on students' procedural knowledge, conceptual knowledge, and motivation after a treatment period over a 14-day duration of a middle school STEM class. The qualitative analysis of transcripts post-study revealed the impact on student perceptions of learning and motivation, and shed light on game features that may contribute to both of these attributes. The computer-based intervention used as supplementary to a traditional lecture and project-based classroom environment took two forms: gaming and non-gaming. Students in the treatment group were introduced to a DGBL platform that utilizes iconic representations of mathematical systems in an engaging and challenging interface. Control group students used two popular non-gaming digital learning sites that are often found in math classrooms, and offer practice and simulation.

The primary purpose of this study was to investigate the impact of DGBL (as separate from non-gaming technologies) interventions on the development of understanding how to solve single-step and multi-step linear equations in procedural and conceptual formats. Additionally, this study aimed to focus on the aspects of motivation that trend toward the development of

situational interest, and to determine if that led to an increase in overall motivation toward mathematics. Simultaneous to the computer-based interventions, the students were receiving instruction in two separate formats: through a traditional lecture math classroom, and through the STEM problem-based classroom. The constructivist approach of the STEM unit that would be presented in conjunction with the digital gaming and non-gaming activities involved inquiry, investigative work on cumulative problems, and sharing ideas with others. Included in Chapter 5 will be a discussion on procedural and conceptual results, motivation towards mathematics and the interest in the supplementary digital activities, the features of the DGBL environment, limitations of the study, and future research.

Research question one: How does digital game-based learning impact procedural and conceptual mathematical understanding among students? Many educational researchers have proposed broad categories of outcomes in an effort to conceptualize learning as a multidimensional construct: skill-based outcomes address technical or motor skills; cognitive outcomes that address knowledge types; affective outcomes that refer to attitudes (Anderson, 2010; Gagne, 1985; Kraiger, Ford & Salas, 1993). Within the cognitive realm, there are subcategories that address the specific type of knowledge that this research was focused on targeting: *procedural* understanding (knowledge about how to perform a task), and *conceptual* understanding (applying learned principles to different contexts). Within each of these knowledge types, there is a range of qualities based on the level at which the student is immersed in the content, from superficial to deep, and require flexibility to devise strategies for solutions (Star, 2005).

To answer the first research question, namely to understand if students using DGBL, compared to a non-gaming supplement, showed significantly higher gains on procedural and

conceptual mathematical problems, two measures were used. The results indicated that, despite the differences in the initial levels of mathematical knowledge, the students showed consistent overall gains in their abilities to solve and simplify linear equations and expressions, although this change could not be contributed to the DGBL environment.

Impact on procedural knowledge. In order to measure procedural knowledge, a researcher-created assessment (Appendix B) was administered. The 10 item test was broken into 4 strands: simplification, solving single-step equations, multi-step equations, and word problems involving linear equations. The procedural items maintained the essence and rigor of the intended questions, but used fewer multiple choice options; a total of two items that had more than one answer. The remaining 8 questions (5 free-response, including 3 word problems) were used to test the relation of algorithmic and rote knowledge of algebraic ideas. The coding remained consistent with the original tool: full credit (2-points) given for a correct answer, partial credit (1-point) given for an incorrect answer with evidence of working through the problem, and no points for an incorrect answer that either lacked a work sample or was not answered. The data for determining the growth in procedural knowledge was collected from pretest to posttest gains, by gathering descriptive data and results from ANCOVA. Quantitative results did not find any significant changes in scores of the procedural mathematics assessment. The supplemental DGBL, Dragonbox Algebra 12+, was not shown to impact the ability of students to solve single-step or multi-step linear equations, or to simplify algebraic expressions.

Although gains were made from pre- to posttest in procedural knowledge, there was not a significant difference in the groups. One reason for the lack of findings could have been that the pacing of the math classes was not consistent from teacher to teacher. This was a variable that was out of the control of the researcher, but from interactions with the students, some expressed

that they were learning linear equations, while others had not been introduced to the new content yet. The threats to internal validity are discussed further in the limitations section as a threat to the validity of the results.

Another potential reason for the lack of significant findings could be that students in the treatment group were not exposed to a method of transferring the learning from the DGBL environment to the classroom environment. The non-game interventions were comprised of various activities that involved practicing algorithms using standard formulas, including direct instruction embedded within the Khan Academy interface. It is possible that the effect of the non-gaming platform may have outweighed the effects of the DGBL platform. The students using the DGBL intervention were exposed to iconic representations of the mathematics through Dragonbox and in an effort to maintain a student-directed experience, the researcher did not intervene with additional instruction or guidance (other than troubleshooting the interface). Combining supplemental instruction from a classroom teacher with the game play of Dragonbox Algebra, could potentially result in greater student achievement gains in procedural understanding. The limited external scaffolding and lack of direct instruction will be discussed further in the Implications for Education section.

Impact on conceptual knowledge. The duration of the 14-day study was comprised of problem-based scenarios in a thematic navigation unit. The entire unit was based on a constructivist approach to developing conceptual understanding of linear equations, through hands-on charting, and manipulating data tables. A pre-assessment of conceptual learning was not administered; rather smaller pieces of formative information was gathered with a summative 2-item assessment (Appendix C) at the end of the unit. Due to the staggering of classes, the final conceptual assessment was given two weeks after each class completed the intervention period.

The time constraints are further discussed in the Limitations section as a threat to the validity of this measurement tool.

Quantitative results suggested that there was not a significant impact on the conceptual understanding of the students from the DGBL environment, as compared to the students in the control group. There was a slight advantage for the treatment group when looking at overall mean scores. It is in the opinion of the researcher that there was not a natural transfer of knowledge from the DGBL platform to the conceptual items. Without the direct instruction to guide the elements of the game back to the problem-based unit of study, the students were not able to make the connection. This issue will be discussed further in the Implications for Education section.

Research question two: How does digital game-based learning affect learners' motivation towards classroom mathematics? Computer games have captured the interest of educators as a means to involve students in an active learner role, and to create learning environments that are less *learning by listening*, and more *learning by doing*. To be able to utilize the motivational properties of video games to enhance academic skills, and develop understanding and awareness of complex topics, is considered the "holy grail" for future educators (Garris et al, 2002). Motivated learners can be thought of as enthusiastic, focused, and engaged. They are interested and enjoy what they are doing; they try hard and persist in their learning over time. This study attempted to show that the level of motivation that a student experiences can be affected by a DGBL environment, and furthermore that that motivation continued over to the mathematics classroom.

In order to determine how DGBL affects learners' motivation towards classroom mathematics, multiple tools were used to measure student response. Prior to the start of the

project, the Student Motivation Survey (Appendix A) was administered to all of the 7th grade students. This measure would serve as a way to explore the shift in motivation from the start of the unit until its completion. The students were instructed by the non-researcher facilitator that the SMS should be answered based on their experience with mathematics in general; for all of the students, the SMS was a measure encompassing two classes during the school day. The post 20-item SMS was administered during the STEM class, following the 14-day intervention.

The second tool that was used to measure motivation (and self-perception of learning) was a post-study questionnaire that would serve to provide evidence in addition to the quantitative data. Different from the SMS by questions that target and isolate the motivation to play from the motivation to learn, the post-study questionnaire filled in some necessary gaps in regards to the gaming versus non-gaming supplements. The students in the control group received a questionnaire (Appendix D) that had language specific to their intervention, while the treatment group had an identical questionnaire (Appendix E) with language that was used to be appropriate for their intervention.

Motivation towards classroom mathematics. The first of two measures was administered to the students prior to the start of the study, and would serve as a baseline for where the incoming students were approaching math from, on an interest standpoint. In contrast to the expectations, the analysis results indicated that there was not statistically significant evidence of an impact to student motivation that could be attributed to the supplementary DGBL environment. There were extraneous variables to consider when looking at the results of the quantitative data that may have affected the outcomes. One important factor to consider was that the Student Motivation Survey was administered in the STEM classroom, but asked the students to answer the questions based on their experience with mathematics in general, except for four

math class specific items. For example, the students were asked to rate, according to their level

of agreement, the statements, "I like it when questions make me think.", or "I like hard,

challenging math problems". The intent was that this line of inquiry would interpret an overall

measure of motivation towards mathematics based on student experience with mathematics in

general. One of the issues with the way that the items were worded was that students had some

confusion as to whether they were answering based on their experience in their math class, or in

their STEM class. The four items that were specific to the math classroom, and that needed to be

clarified by the non-researcher facilitator was, "Our class is fun.", "This year I like math.", "I

look forward to finding out my math grade.", and "I actually look forward to going to math class

this year." An item analysis of these items specifically showed no significant evidence of impact

from the DGBL intervention.

A second factor to take into account when analyzing the results was that having math

embedded within the STEM class was a new experience for the 7th grade students, and one that

seemed to cause some confusion and frustration. All students would be enrolled in math class,

and either followed or preceded by the STEM class. Many of the students interpreted this as a

double-dose of mathematics within one school day, as there was no structural precedent with

their previous experiences of the anticipated middle school course load. Anecdotal evidence to

support this claim was made by comments like, "Why do we have to take two periods of math?",

and "Can we not do anymore math today?".

A limitation to the results of the SMS that needs to be addressed is that the total scores of

several students are inaccurately underestimated/overestimated because of missing data. On the

pre-study survey, there were twelve students who did not answer 100 percent of the items (ten

students left 1 item blank, two students left 2 items blank). On the post-study survey, this

number decreased (due to a reminder from the proctor prompted by the researcher in response to the issue). Seven students failed to answer all of the items (five students left 1 item blank, two students left 2 items blank). In order to keep all of the data, and not eliminate students from the population, it was decided to use the mean item result of the other students in their assigned group (treatment or control), and use it to estimate an appropriate value. The average imputation does reduce the overall variability of the data, but because of small amount of missing data it was easy to implement and did not change the significance of the data (compared to when the students were removed completely).

Self-perception of achievement in the DGBL environment. The items developed for the post-study questionnaire were targeted specifically to address characteristics of situational and individual interest (Mitchell, 1993), and self-perception of interest and engagement, enjoyment, and feelings of mastery (Garris et al, 2002). According to work on the construct of motivation in the mathematics classroom, there are facets of gaining attention of a student (group work, puzzles, computers), separate from empowering the student (meaningfulness, involvement). Questions were categorized based on the elements of motivation and situational interest they contained. The Input-Process-Outcome Game Model presented in chapter 3 (Figure 1), described the flow in a DGBL environment with reference to *User Judgement* as part of the process loop. Interest, task involvement, enjoyment, and confidence are all factors of motivation that can be identified in the questionnaire items, and are encompassed in the subjective judgements of the students.

In addition to looking at measures of interest and achievement, the questionnaire would also serve to provide a comparison between the gaming and non-gaming supplements. As bargain bins and sale items can attest, there are many educational games that lack appeal and

instructional value. Digital learning platforms and game features that do not engage learners, or produce learning outcomes, are difficult to justify in an educational setting, therefore a closer look at the type of digital platform that may be of interest to students is relevant in this study.

The first item on the questionnaire was based solely on the attitude towards the use of supplementary digital interventions used as part of STEM class. Students would indicate their agreement to the statement: "*I looked forward to the days that we used computers as part of STEM class*" by using a 5-point Likert scale that ranged from strongly disagree, disagree, neutral, agree, and strongly agree. The statement was developed with the intention of determining if the use of computers and individual involvement were motivating factors for the students (Mitchell, 1993). In work on situational interest, Mitchell (1993) describes elements of "catching" as finding various ways to stimulate students, while "holding" involves variables that empower students. The use of computers can be classified as a *catch*, while student involvement is an important element of the *hold*. According to the results of the survey, 86 percent of students in the treatment group ($n = 44$) agreed to the statement regarding the DGBL environment, as opposed to 56 percent of the control group ($n = 39$). Of the percentage of students in the treatment group who indicated that they *agree* with the statement, 55 percent indicated that they *strongly agree*, compared with 41 percent of the control group. Although the data from the Student Motivation Survey did not support the hypothesis that use of DGBL increased a student's motivation towards classroom mathematics, the results from the questionnaire provided a different view. A possible reason for the discrepancy of the data could be that the SMS was more general to mathematics class, while this question was specific to only the STEM class in which the technology was being utilized as supplementary to the problem-based mathematics curriculum.

The students were asked to rate their experience with the gaming and non-gaming environments to get a measure of the general enjoyment of the intervention, with the question, "*How would you rate your experience with the Dragonbox/Khan Academy/Desmos activities?*". The 5-point Likert scale ranged from strongly negative, negative, neutral, positive, and strongly positive. Although the enjoyment of the DGBL environment may not necessarily be related to learning or retention, the measure would serve to disaggregate the type of intervention: gaming or non-gaming. The treatment group (82 percent) reported that they had a more enjoyable experience with the game than did the control group when compared to Khan Academy supplements (18 percent). This serves as an example of a strictly gaming versus non-gaming comparison; while students rated their experience as positive with the non-gaming interactive simulation supplement as much higher (54 percent). The significance of this finding should be examined further as to how best to support the differing platforms to serve students based on content needs, and will be discussed in the Implications for Education section.

Student responses to the question, "*Compared to other lessons, how much math do you think that you learned by using interactive simulations?*" ranged from a lot less, less, neutral, more, and a lot more. This question was based on research on game features embedded within DGBL intended to improve motivation and cognition (Belland et al, 2013), and feelings of mastery (Garris et al, 2002). The inclusion of this item was to determine a student's expectancy for success, measured through their interaction with the digital software, specifically feedback and learner supports. The results were fairly similar in both groups, indicating that the students were mostly neutral, with less than half of each group identifying that they had learned *more* or learned *a lot more* by using the gaming and/or non-gaming interventions. Of the 19 students in the treatment group that answered they had learned *more* or *a lot more,* 32 percent were in the

higher range, compared with 14 percent of the control group. This is further supported by anecdotal evidence from the open-ended response items from Chapter 3 (Table 10) in which the majority of the negative responses were based in the transfer of knowledge category, and described issues relating the supplement back to mathematics. The role of external scaffolds and instructional supports to facilitate transfer will be discussed further in the Implications for Education section.

The students were invited to explain their answer and provide an example once they had rated the item regarding the effectiveness of learning math from the digital learning environment. After initial coding and development of categories, there were themes that emerged to tell a story of the student's experience with the intervention. These themes were inductively developed with the Input-Process-Outcome Game Model, specifically *Interface Characteristics, System Feedback, Learning Outcomes,* and motivation research including scaffolding strategies, specifically promoting autonomy. Within the entire population, 49 percent of the students had comments that were only framed in the positive regarding the intervention. In terms of transferring knowledge, the overall theme of the transcripts was that the treatment group had a much more difficult time relating their game to solving math problems. With the absence of direct instruction to support the transfer, these results seemed consistent with the data gathered on achievement and the self-report in the neutral ranges. The control group responses supported their self-reporting that video games and computer simulations help the learning process, but the negative comments were rooted in the idea that they were getting too much math. Looking at the accessibility of content, the students in the treatment group enjoyed the style of learning that fit with their system and were able to identify the features that were helpful. The students in the control group had much more to say about this category, and didn't seem to like the format of

Khan Academy, as evidence by statements like, "wasn't a good fit", "groups are better", and "I need hands-on". The theme of developing understanding was closely linked with the theme of transferring knowledge, but there were clear indicators of students who could provide examples to showcase their learning and explain the transfer, and those who used comparative phrases, such as, "it's easier to learn", "I can learn better", and "it helps me to understand". There were mixed results in the transcripts, and many of the students (from both groups) had difficulty with the interventions, and found them confusing or not helpful. The final theme was in regards to the game characteristics that are intended to support learning and effect motivation. The students involved in the DGBL seemed to narrow in on the exact features of the game (characters and esthetic elements of the interface), while students using the non-gaming platforms addressed the general idea that the interface grabbed their attention. On the negative side, both groups addressed the interface as "boring", "just sliding boxes around", and "too slow". The responses referring to interface characteristics echoed a frustration with an over-simplified, and unengaging platform. Although there were comments expressing positives in terms of the visuals, the language used to describe was void of any real examples of the digital environments. Game characteristics will be addressed further in the Implications for Education section.

The final item on the questionnaire asked the students to indicate their level of agreement with the statement: "*Video games and computer simulations help me to learn*.", by using a 5-point Likert scale that ranged from strongly disagree, disagree, neutral, agree, and strongly agree. Continuing to use the process of game play and factors within this process that contribute to motivation to learn, the self-reporting of this item was intended to measure the task involvement leading to confidence (Belland et al, 2013; Garris et al, 2002; Hidi & Harackiewicz, 2000). The results of the ANOVA did not find that the differences between groups were statistically

significant, and similar to the results that asked the students to compare the effectiveness of learning with other non-digital lessons, there was very little difference in the overall mean scores. The mean scores for both the treatment and the control groups ranged between *neutral* and *agree*, with the control group having a slightly higher percentage of students that responded in the positive (67 percent) compared to the treatment group (55 percent). A potential reason for this result might be that the students have a somewhat easier time transferring knowledge when it looks similar to what they are doing in class. The control group had several practice activities and simulations in their intervention, as opposed to the DGBL environment that requires the user to transfer their analogical thinking.

The balance between instructional and enlightening DGBL with engaging and exciting is an exactness that has not been determined with this study. Creating learning environments that utilize interactive technologies to actively involve students in problem-solving, and promote self-directedness by proper utilization of game characteristics will be discussed further in the Future Research section.

Research Study Limitations

Given the limitations of quasi-experimental research, this study's outcomes in both mathematical understanding and motivation impacts should be interpreted with two lenses: one of a researcher and the other, of an educator. Limitations addressing the changes made to the study from the original planning and methodology and those when working within a classroom environment and maintaining internal and external validity will be presented. There were several limitations to this study that the researcher was aware of from the start of the treatment period. One of the limitations of this study was the small sample size which reduced the researcher's ability to detect effects. Initially, this study was planned with 87 students participating,

representing 100% of the seventh grade students at the middle school. Due to multiple absences and inconclusive data from some students, the total population was 77 students. With this small sample size, and the additional grouping of students into the control ($n = 37$) and treatment ($n = 40$), limits detecting statistically significant differences between measures, and may lead to Type II error. There is a need to replicate this study with a larger sample to provide additional evidence of the impact of DGBL.

The short time frame was an additional limitation, that, with further study, could be investigated at varying lengths to determine an appropriate amount of time to allot to DGBL interventions. Fourteen classroom periods, at 55 minutes each, were allotted to complete this study. The limited time-frame was determined by the Portland Public School mathematics curriculum planning calendar, and also by teacher staffing and distribution throughout the 7th grade classes. Attempting to coordinate with multiple staff members to keep scheduling consistent, decisions were made on behalf of student need as opposed to researcher need, and may have led to inconsistencies with data collection.

There were several extraneous variables that were not able to be controlled for that may have jeopardized the internal validity of the quantitative and qualitative data: class size, differing teaching styles, different pacing, room and scheduling changes. After some changes between math groups there were ($n = 35$) students enrolled in the compacted class that were sometimes given math instruction in one whole group, and other times, split between two math teachers. The students in the grade level class ($n = 42$) were broken into two smaller classes, and each of those classes had a more consistent schedule and routine. Due to staffing issues, these classes changed hands between the math teachers, until additional support could be proposed that allowed for accommodation for student class size adjustments. Although the district has a

pacing calendar, there was not strict adherence among all groups and teachers as to what unit they would be teaching, when, or for how long. This decision was left up to the individual teachers with the understanding that the content will be covered during the course of the year, but pacing would be based on their classes and the needs of the students. Therefore, some of the groups had information different from their peers, and had been exposed to material that was not consistent within the entire population. There was a scheduling switch in mid-September, that moved both periods of math and STEM rotations to the last part of the school day from the previously earlier slot. At the start of the school year, and the intervention, the classes met from 12:10-1:10, and 1:15-2:15; with the change the new times were 1:10-2:10, and 2:15-3:15. Traditionally in the middle school at SES, the last hour of the day was reserved as the core/homeroom class, and the change in time seemed to be impact the overall flow of the day-to-day routine for an initial period of adjustment.

A common limitation in educational settings that is out of the control of the researcher, but impacted class on a daily basis, is absenteeism among students. A record of attendance was maintained by the teacher-researcher to track the students who were absent, tardy, and present, but there were many inconsistencies due to events, meetings, and requests that prevented a consistent record. Because attendance is only taken in the core (homeroom) classrooms, a daily attendance is not required in the afternoon periods. Attendance was not considered in the analysis because it was determined based on the levels attained through the DGBL/Khan/Desmos interfaces, that all students had completed the activities assigned to them. Through Khan Academy and Desmos, the researcher has access to all student account activities, and was able to monitor the completion. Oftentimes this took place in their regular math class with time provided to them per their math instructor. The treatment group was not given additional time to

complete activities due to the fact that the computers were being borrowed from other grades and classrooms that we had limited access to. The students using Dragonbox completed each level, with opportunities to revisit levels that they had lower scores in. Based on the ability for all students to complete their intervention, the attendance data was not taken into account during analysis.

In addition to the issues with conducting a research study through a large public institution (the school district), with many uncontrolled factors, there were also some limitations that were harder to control at the local level. The limitations in terms of the measurement of conceptual understanding were numerous: the maturation time between the intervention and the distribution of the assessment (approximately 3 weeks), the added selection bias (convenience sample) from the students of the population of which the researcher had access to, and the lack of a conceptual pre-test to control for external factors. The assessment was administered to 65 percent of the total population of 7th grade students, and the distribution of students from the treatment and control groups that were identified as compacted math or grade-level math was uneven.

Implications for Education

The intent of this research was to add to the field of knowledge about the use of supplemental DGBL to support learning achievement and motivation. The results of the study were unable to support the hypotheses that DGBL promotes greater understanding of procedural and conceptual knowledge or motivation towards mathematics, yet there were implications for education that cannot be ignored.

Based on interactions and informal observations of the students during the process, there was enthusiasm towards the 14-day unit of study, particularly the days that the students would be

using computers, and specifically from those who would be playing Dragonbox Algebra. On the days that the students would be working on their unit and using math to solve problem-based scenarios, there were numerous complaints and expressed frustration that they were exposed to too much math in one day. The idea of expanded instructional time has been proposed to remedy limited mathematical achievement, and improve academic outcomes of low performing students (Nomi & Allensworth, 2009). Although the STEM class is not technically *math* class, the students expressed their displeasure with the double math blocks at the end of each day, and this may have severely affected their motivation scores. Based on this study, the implications for education are two-fold in terms of motivation: while students may react enthusiastically to video games, this does not necessarily equate to a motivation for mathematics, and a double-dose of math classes might counteract the developing situational interest of a student. The discrepancy in data from the motivation survey and the post-study questionnaire regarding how much enjoyment students experienced in class might be attributed to the fact that the intervention was being carried out in STEM class, while their math class was more of a traditional lecture format. It was outside the scope of this study to consider the variables of the students' math classes that might have been factors in their motivation towards mathematics in general.

Another possible conclusion to the limited motivation effects was that there was not enough of a treatment dosage to actually have an effect. The students were given 120 minutes of supplementary intervention in the DGBL environment. Much of this time was used by attempting challenges, and revisiting previous challenges that were not successfully completed. Students did not yet fully grasp a facility in working with iconic representations for integers and variables. Some of the student answers on the post-assessment used illustrations of images from the Dragonbox game board in showing a solution. These were only in response to two problems

from two separate students to illustrate the answer to a single-step equation, and therefore did not seem to be a connection that many of the students made. Transfer of learning from the DGBL environment to the tasks that the students are asked to perform in class is essential to make full use of the supplemental intervention. While students can express interest in an alternative mode of instruction, and seem immersed in the digital realm, this does not necessarily transfer back into their classwork without some direct instruction of how to apply the gaming concepts into their schema. Although games can be effective in enhancing motivation and increasing student interest in subject matter, the extent to which this translates into more effective learning is less clear. A debriefing phase to support the transfer of knowledge from a game or interactive simulation may be part of the effective instruction that can lead to learning outcomes.

An interesting implication to be made was that the students that were part of the control group used an intervention that had embedded within it direct instruction of procedures to solve problems presented to them. In lieu of classroom instruction, this served to offer these students more of an instructional base with which to solve algebraic equations. The students in the treatment group lacked the additional explanations on procedural learning within their DGBL environment, but based on the results of the procedural knowledge assessments, did not differ significantly from their control group peers. Ruipérez-Valiente, Munoz-Merino, Leony, and Kloos (2015) found that users ($n = 372$) on Khan Academy spend time on the site in both the video tutorials and the practice exercises, but have a high percentage of abandoning or not completing activities. In their research, 60 percent of the exercises that were started by students were abandoned, and it was further noted that although the user has completely seen the videos available in the course, they are struggling in exercises, and then not completing them. Even though additional instruction was available to students in the control group, combined with

practice opportunities, this did not seem to drastically distinguish them from their peers in the DGBL environment.

Procedural and conceptual understanding as part of a mathematics curriculum is necessary to help the students create a meaning for the problems that are posed in an algebra class. Looking at the way that students approach procedural problems using a series of prescribed steps to determine a solution, does not automatically lead them to understanding how or when to apply these problems in the context of a real-world problem. Using the STEM class as an avenue to deliver math in a problem-based format required confidence in procedural knowledge to problem solve. The DGBL and non-gaming environments were useful in providing a medium in which to explore how to manipulate and solve different types of equations. When tasked with applying this knowledge to larger, more complex problems, there was confusion and a disconnect with material that had been learned and when or how to apply it. Based on the difficulty with the conceptual task, it seemed apparent that explicit connections must be made not only with the supplemental interventions, but also with how the procedural pieces fit in with the conceptual.

Future Research

In light of the limitations of this study, in addition to the lack of statistically significant findings, the need for further research in DGBL environments is necessary. There are two main areas of focus to explore: the transfer of learning and game design. Looking at the potential for education reform around technology enhanced learning means redefining what learning looks like. There is a need to conduct further research to examine how other human factors, such as cognitive styles, ethnicity, and gender differences, affect learners' reactions to digital games, and then base a variety of supports and designs accordingly.

In order for students to develop higher-level thinking skills, the activities that are used must be conceptually within the grasp of the students given their existing knowledge base, and scaffolds put in place to assist in making connections. Student support within the DGBL environment, and as part of an external debriefing process, is an area of future study. Proper scaffolding that incorporates each student's learning potential embedded within the DGBL environment may be necessary for this type of supplement to be most effective. Research on the types of learner supports that promote the transfer from procedural to conceptual understanding, with explicit use of game elements as part of assessments, might serve to better facilitate the DGBL environment. Educational research could investigate interactions and dependencies between promising variables internal and external to the gaming environment, and the impact on achievement and the cognitive processes that are employed while playing the game. Research focusing on whether students are able to transfer these processes to non-game situations, such as real-world mathematics problems or standardized tests, would be valuable.

One can only speculate as to what the rapidly changing, and endlessly creative, game development industry has in the works. As games become more realistic, experiential, and immersive, players are transported into virtual worlds that they control and learn from. The ability to communicate and play with others thousands of miles from ourselves makes this new frontier full of human interaction, and the elements of communication and cooperation are becoming just as important as competition. Collaboration with peers over a common platform could serve to connect each other in ways that would strengthen our knowledge base and provide us with resources that reach far outside of the walls of the brick and mortar school. With gaming reaching millions of users, new forms of play and diverse subject matters have started to emerge that allow individuals to have new types of experiences that cannot be found elsewhere. Finally,

the engagement element that is currently part of the player experience will only become more enhanced with virtual reality and sense stimulation are going to further redefine the virtual world. As these experiences become more useful, and with compelling, they have the potential to transform the learning environment. An area of future need is in relation to the development of games marketed for DGBL purposes that utilize educators as co-creators to support the embeddedness of curricular objectives within the game. Game design that provides a context with which to apply learned procedures and develop conceptual understanding are already marketed for entertainment in a variety of genres. The hours of gameplay required to complete advanced games can far surpass the hours spent in a traditional classroom, with much of this time spent in a state of engagement. Based on the way that users interact with their technologically driven environment, it would be valuable to make this environment educational and a means with which to deliver content in language arts, mathematics, science, social studies, and more. A possible area of future need, as educators become part of the design process, is to develop assessments embedded within the games themselves as part of the design features. As users move throughout the DGBL environment, and complete challenges, they are essentially completing *lessons*; these lessons are already delivered in a context that the user is immersed in.

Conclusion

There are numerous concerns in our contemporary educational system: financial, cultural, political, and other distinct issues. Policies and practices that affect students need to be developed with multiple perspectives of learning in mind. One-sided practices that ignore the ways in which learners have changed over time are not part of solid pedagogical philosophies of the 21st century. Using digital media technologies for effective learning and supporting teaching practices has the potential to reach the learners of today as more of just a tool of one-way

communication. Living in a time in which digital media and technology has become such a large part of our lives has opened the door for individuals to have access to knowledge through multiple points of access. The potential of digital media and technology to transform the imaginations of our learners has yet to be discovered. The roles played by various forms of technology are that of tutor, information supplier, communications facilitator, motivator, competitor, the stimulator of a specific thought or activity, and more. Looking specifically at Digital Game-Based Learning as impactful to education and classroom learning, there are three features that make it hard to ignore: (a) DGBL meets a wide variety of needs and leaning styles of present and future generations of learners, (b) DGBL is motivating, and (c) DGBL is versatile, and adaptable to almost any subject. Communications theorist, Marshall McLuhan (1967), stated that "Anyone who thinks there is a difference between education and entertainment doesn't know the first thing about either."

As discussed in Chapters 1 and 2, the benefits of integrating digital media and technology into today's curriculum has become a focus of many educator's attention, and the potential to foster student achievement and motivation is the subject of numerous studies. Through different lenses, evidence has been found that continues to promote the use of properly used technologies, as beneficial for learners. Based on research and evidence in neurology, the various types of stimulation actually change brain structures and affect the way people think. Brain plasticity research demonstrates the ability of the brain to be malleable and responsive to the environment by altering its structure based on inputs. These changes come in the form of parts of the brain being "lit up" and activated during certain activities, much like an exercise being performed on specific muscles to strengthen them. One aspect of plasticity within the visual cortex (an area of the brain highly effected in gaming studies) is the augmentation of skills in reading visual images

as representations of three-dimensional space and the increased ability to decode iconic representations of graphics (Greenfield, 2014 ; Prensky, 2001).

Looking at learning through the lens of an educator there is a massive range of learning styles and abilities to consider in classrooms. There are two major factors that this research is focused on through this lens: content knowledge and student motivation. When condensing this view even further, in terms of content knowledge, the student capacity for mathematical thinking and reasoning is an area in which there is a need for special attention based on evidence of students falling behind in terms of academic achievement. The entanglement between the balance of procedural knowledge and conceptual knowledge, and specific qualities that define each is an area of future need in the field of mathematics education research. Limited proficiencies in procedural understanding limits grasping conceptual, and at the same time, lack of transfer from procedures to deep problem solving prevents contextual experiences and removes meaning from the content. While DGBL has attempted to remedy the limited proficiencies in mathematics, the focus has been predominately on procedures and recall of facts. Reforming mathematics education based on the needs of the students of today means more than just further instruction on how to manipulate equations. As demonstrated in research presented in the literature review, there is considerable interest in the field of technology enhanced learning and plenty of room for DGBL to grow and be applied in mathematics classrooms to eventually positively impact academic achievement in mathematics. While data from this study might not provide sufficient evidence to make the claim that DGBL can significantly impact motivation and mathematical understanding, it has provided some starting points for future research.

The second area of focus from the lens of an educator is that of student motivation and interest. The procedural and conceptual knowledge debate can rage on, but without student

interest, or the motivation to learn, who is learning the content being delivered? Chapter 2

provided research on the how technologies (computers, video games) can stimulate the interest

of students, and impact motivation and student attitudes towards mathematics. DGBL

environments that incorporate elements of external student support along with principles of good

game design have the potential to transform the learning experience of the 21st century. Master

game architect and Google's former Chief Game Designer, Noah Falstein, has taken his

approach to gaming design and branched into the maturing field of health and neuroscience

games. One of his recent projects has transformed the confluence of games, neuroscience, and

three-dimensional graphics into a computerized medical training system to train physicians on

patient care (U.S. Patent No. 8,469,713 B2, 2013). Many of the embedded elements of popular

game design, are used in the virtual clinical setting, and serve to provide an enjoyable and

motivating experience in the form of personal avatars, clear objectives, attainable challenges,

individual feedback, and increasing the user status based on performance (Prensky, 2001; U.S.

Patent No. 8,469,713 B2, 2013). These game design principles foster learner motivation, and

then further allow the user to construct their own learning as an agent inside the virtual space,

and therefore create opportunities to apply their existing knowledge to new situations to develop

conceptual understanding.

This study addressed the impact of DGBL on procedural and conceptual understanding

and motivation towards mathematics. Digital media and technology enhanced learning offer the

opportunity for learners to engage with learning by doing, while experiencing learning in an

authentic and interactive environment. Learning in the digital age should not only be limited to

using software packages that are free, popular, and mimic what a teacher does in a classroom

with lecture-based formats and practice sets. DGBL is making headway as an equally effective

technology compared to many of the popular digital lectures and exercise activity sites. Diverse new concepts in teaching and new digital tools will change the educational landscape for young learners in the technology-driven age of today and for the future. The task for educators at the present is not only to use these tools effectively as part of instruction, but to review and design innovative educational approaches supporting students in their use of digital media and technology in the 21st century, to create the learners of the future.

References

American Association of School Librarians (2018). *National school library standards: Standards framework for learners.* Retrieved from http://standards.aasl.org/wp-content/uploads/2017/11/AASL-Standards-Framework-for-Learners-pamphlet.pdf

Abdelhafez, A. (2016). *The effects of game-based technology on high school students' algebraic learning in an urban school classroom* (Doctoral dissertation). Retrieved from http://search.proquest.com/docview/1865956661

Afari, E., Aldridge, J., Fraser, B., & Khine, M. (2013). Students' perceptions of the learning environment and attitudes in game-based mathematics classrooms. *Learning Environments Research, 16*(1), 131-150. doi: 10.1007/s10984-012-9122-6

Ainsworth, S., Bibby, P., & Wood, D. (2002). Examining the effects of different multiple representational systems in learning primary mathematics. *Journal of the Learning Sciences, 11*(1), 25-61. doi:10.1207/S15327809JLS1101

Allensworth, E., Montgomery, N., Lee, V. E., & Nomi, T. (2009). College preparatory curriculum for all: Academic consequences of requiring algebra and English I for ninth graders in Chicago. *Educational Evaluation and Policy Analysis, 31*(4), 367-391. doi:10.3102/0162373709343471

Ames, C., & Archer, J. (1988). Achievement goals in the classroom: Students' learning strategies and motivation processes. *Journal of Educational Psychology, 80*(3), 260-267.

Ames, C. (1984). Achievement attributions and self-instructions under competitive and individualistic goal structures. *Journal of Educational Psychology, 76*(3), 478-487.

Ames, C. (1992). Classrooms. *Journal of Educational Psychology, 84*(3), 261-271. doi:10.1037/0022-0663.84.3.261

Anderson, J. R. (2010). *Cognitive psychology and its implications* (7th ed.). New York, NY: Worth Publishers.

Anguera, J., & Gazzaley, A. (2015). Video games, cognitive exercises, and the enhancement of cognitive abilities. *4*, 160-165. Retrieved from https://doi.org/10.1016/j.cobeha.2015.06.002

Antonenko, P., Paas, F., Grabner, R., & van Gog, T. (2010). Using electroencephalography to measure cognitive load. *Educational Psychology Review, 22*(4), 425-438. doi: 10.1007/s10648-010-9130-y

Bach, T. (2011). Structure-mapping: Directions from simulation to theory. *Philosophical Psychology, 24*(1), 23-51. doi:10.1080/09515089.2010.533261

Barab, S. A., Gresalfi, M., & Ingram-Goble, A. (2010). Transformational play: Using games to position person, content, and context. *Educational Researcher, 39*(7), 525-536. doi:10.3102/0013189X10386593

Baroody, A., Feil, Y., & Johnson, A. (2007). *An alternative reconceptualization of procedural and conceptual knowledge*. Washington: National Council of Teachers of Mathematics. Retrieved from http://www.jstor.org/stable/30034952

Barzilai, S., & Blau, I. (2014). Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. *Computers & Education, 70*, 65-79. Retrieved from http://dx.doi.org/10.1016/j.compedu.2013.08.003

Baxter, J. A. (2005). Some reflections on problem posing: A conversation with Marion Walter. *Teaching Children Mathematics, 12*(3), 122. Retrieved from https://search.proquest.com/docview/214135151

Bayart, C., Bertezene, S., Vallat, D., & Martin, J. (2014). Serious games: Leverage for knowledge management. *The TQM Journal, 26*(3), 235-252. doi:10.1108/TQM-12-2013-0143

Belland, B. R., Kim, C., & Hannafin, M. J. (2013). A framework for designing scaffolds that improve motivation and cognition. *Educational Psychologist, 48*(4), 243-270. doi:10.1080/00461520.2013.838920

Belland, B. R., Walker, A. E., & Kim, N. J. (2017). A Bayesian network meta-analysis to synthesize the influence of contexts of scaffolding use on cognitive outcomes in STEM education. *Review of Educational Research, 87*(6), 1042-1081. doi:10.3102/0034654317723009

Belland, B. R., Walker, A. E., Kim, N. J., & Lefler, M. (2017). Synthesizing results from empirical research on computer-based scaffolding in STEM education. *Review of Educational Research, 87*(2), 309-344. doi:10.3102/0034654316670999

Bennett, S., Maton, K., & Kervin, L. (2008). The digital natives debate: A critical review of the evidence. *British Journal of Educational Technology, 39*(5), 775-786. doi: 10.1111/j.1467-8535.2007.00793.x

Bottino, R.M., & Ott, M. (2006). Mind games, reasoning skills, and the primary school curriculum. *Learning, Media and Technology, 31*(4), 359-375. doi:10.1080/17439880601022981

Cameron, B., & Dwyer, F. (2005). The effect of online gaming, cognition and feedback type in facilitating delayed achievement of different learning objectives. *Journal of Interactive Learning Research, 16*(3), 243-258. Retrieved from https://search.proquest.com/docview/1468383383

Camli, H., & Bintas, J. (2009). Mathematical problem solving and computers: Investigation of the effect of computer aided instruction in solving lowest common multiple and greatest common factor problems. International Journal of Human Sciences, 6, 348-356.

Canada, G. (2013). *Our failing schools. Enough is enough!* [Video file]. Retrieved from https://www.ted.com/talks/geoffrey_canada_our_failing_schools_enough_is_enough?utm_c ampaign=tedspread&utm_medium=referral&utm_source=tedcomshare

Cates, W. M., & Bruce, R. R. (2000). Conceptualizing learner support space. *Educational Technology Research and Development, 48*(1), 85-98. doi: 10.1007/BF02313487

Cavanaugh, J. M., Giapponi, C. C., & Golden, T. D. (2016). Digital technology and student cognitive development. *Journal of Management Education, 40*(4), 374-397. doi:10.1177/1052562915614051

Chang, K., Wu, L., Weng, S., & Sung, Y. (2012). Embedding game-based problem-solving phase into problem-posing system for mathematics learning. *Computers & Education, 58*(2), 775. doi: 10.1016/j.compedu.2011.10.002

Chien, M. (2012). *Digital medias transformative role in education: Beyond potential to essential* (Doctoral dissertation). Retrieved from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2320122

Creswell, J. W. (2009). *Qualitative inquiry and research design* (2. ed., [Nachdr.] ed.). Thousand Oaks [u.a.]: Sage.

Culp, K. M., Honey, M., & Mandinach, E. (2005). A retrospective on twenty years of education

   technology policy. *Journal of Educational Computing Research, 32*(3), 279-307.

   doi:10.2190/7W71-QVT2-PAP2-UDX7

Davis, R. B. (1992). Reflections on where mathematics education now stands and on where it

   may be going; In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and*

   learning: A project of the national council of teachers of mathematics (pp. 724-734). New

   York: Macmillan.

De Smedt, B., Ansari, D., Grabner, R. H., Hannula, M. M., Schneider, M., & Verschaffel, L.

   (2010). Cognitive neuroscience meets mathematics education. *Educational Research*

   Review, 5(1), 97-105. doi:10.1016/j.edurev.2009.11.001

Dessoff, A. (2010). Google and Microsoft go to school. *The Education Digest, 76*(4), 4-7.

   Retrieved from https://search.proquest.com/docview/819517139?accountid=14703

Dewey, J., Dewey, E. (1915). *Schools of to-morrow*. New York, NY: E.P. Dutton & Company.

Domina, T., McEachin, A., Penner, A., & Penner, E. (2015). Aiming high and falling short.

   Educational Evaluation and Policy Analysis, 37(3), 275-295.

   doi:10.3102/0162373714543685

Downes, J. M., & Bishop, P. (2012). Educators engage digital natives and learn from their

   experiences with technology. *Middle School Journal, 43*(5), 6-15.

   doi:10.1080/00940771.2012.11461824

Duggan, M. (2015, Dec. 15). *Gaming and gamers.* Retrieved from PEW Research Center

    website: http://www.pewinternet.org/2015/12/15/gaming-and-gamers/.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced*

    Nursing, 62(1), 107-115. doi:10.1111/j.1365-2648.2007.04569.x

Foehr, U. G. (2006). *Media multitasking among American youth: Prevalence, pairings and*

    predictors (Doctoral dissertation). Retrieved

    from http://www.riss.kr/pdu/ddodLink.do?id=T11139826

Friedlander, A., & Arcavi, A. (2012). Practicing algebraic skills: A conceptual approach.

    Mathematics Teacher, 105(8), 608-614. doi:10.5951/mathteacher.105.8.0608

Gagne, R.M. (1985). *The conditions of learning and theory of instruction.* New York, NY:

    Holt, Reinhart & Winston.

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: A research and

    practice model. *Simulation & Gaming, 33*(4), 441-467. doi:10.1177/1046878102238607

Gazzalley, A (2015) *Promise of tech and the brain* [Video file]. Retrieved from

    http://www.tedxsonomacounty.com/

Gazzalley, A., & Rosen, L. (2016). *The distracted mind: Ancient brains in a high-tech world.*

    Cambridge, Massachusetts: MIT Press.

Gee, J. P. (2007). *What video games have to teach us about learning and literacy.* New York,

    N.Y.: Palgrave Macmillan.

Gee, J. P. (2005). Good video games and good learning. *Phi Kappa Phi Forum, 85*(2), 33.

    Retrieved from http://search.proquest.com/docview/235184729

Gentner, D. (1983). Structure-Mapping: A theoretical framework for analogy. *Cognitive Science,*

    7(2), 155-170. doi:10.1207/s15516709cog0702_3

Green, C. S., Li, R., & Bavelier, D. (2010). Perceptual learning during action video game

    playing. *Topics in Cognitive Science, 2*(2), 202-216. doi:10.1111/j.1756-8765.2009.01054.x

Greenfield, P. M. (2014). *Mind and media: The effects of television, video games, and computers*

    (Classic ed.). New York, NY: Psychology Press.

Habgood, M. P. J., & Ainsworth, S. E. (2011). Motivating children to learn effectively:

    Exploring the value of intrinsic integration in educational games. *Journal of the Learning*

    Sciences, 20(2), 169-206. doi:10.1080/10508406.2010.508029

Hainey, T., Connolly, T. M., Boyle, E. A., Wilson, A., & Razak, A. (2016). A systematic

    literature review of games-based learning empirical evidence in primary education.

    Computers & Education, 102, 202-223. doi: 10.1016/j.compedu.2016.09.001

Herold, B. (2014). *Chromebooks gaining popularity in districts*. Bethesda: Editorial Projects in

    Education. Retrieved from http://search.proquest.com/docview/1627088757

Hidi, S., & Harackiewicz, J. M. (2000). Motivating the academically unmotivated: A critical

    issue for the 21st century. *Review of Educational Research, 70*(2), 151-179.

    doi:10.3102/00346543070002151

Hiebert, J., & Lefevre, P. (1986). Conceptual and procedural knowledge in mathematics: An introductory analysis. *Conceptual and procedural knowledge: The case of mathematics*. Hillsdale, NJ: Erlbaum.

Hommel, M. (2010). Video games and learning. *School Library Monthly, 26*(10), 37. Retrieved from http://search.proquest.com/docview/347842388

Howard-Jones, P., Holmes, W., Demetriou, S., Jones, C., Tanimoto, E., Morgan, O., . . . Davies, N. (2015a). Neuroeducational research in the design and use of a learning technology. *Learning, Media and Technology, 40*(2), 227-246. doi:10.1080/17439884.2014.943237

Howard-Jones, P., Ott, M., van Leeuwen, T., & De Smedt, B. (2015b). The potential relevance of cognitive neuroscience for the development and use of technology-enhanced learning. *Learning, Media and Technology, 40*(2), 131-151. doi:10.1080/17439884.2014.919321

Hsieh, H., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research, 15*(9), 1277-1288. doi:10.1177/1049732305276687

Hwang, Gwo-Jen, Wu Po-Han, & Chen Chi-Chang. (2012). An online game approach for improving students' learning performance in web-based problem solving activities. *Computers & Education,* doi:10.1016/j.compedu.2012.05.009 10.1016

Illeris, K. (2009). *Contemporary theories of learning* (1st publ. ed.). London, England: Routledge.

IT spending of US higher education institutions to reach $6.6 B in 2015. (2015, May 11).

Electronic Industry News. Retrieved from

https://ein.iconnect007.com/index.php/article/90040/it-spending-of-us-higher-education-to-

reach-66b-in-2015/90043/?skin=ein

Keene, K. (2013). Blending and flipping distance education. *Distance Learning, 10*(4), 63.

Retrieved from https://search.proquest.com/docview/1496655665

Keller, John M. (1987). Development and use of the ARCS model of instructional design.

Journal of Instructional Development, 10(3), 2-10. doi:10.1007/BF02905780

Kraiger, K., Ford, J. K., & Salas, E. (1993). Application of cognitive, skill-based, and affective

theories of learning outcomes to new methods of training evaluation. *Journal of Applied

Psychology*, *78*, 311-328. doi: 10.1037/0021-9010.78.2.311

Krapp, Andreas. (1999). Interest, motivation and learning: An educational-psychological

perspective. *European Journal of Psychology of Education, 14*(1), 23-40.

doi:10.1007/BF03173109

Kron, F.W., Falstein, N, Marsella, S. (2013). *United States Patent No. US8,469,713 B2*.

Washington, DC: U.S. Patent and Trademark Office.

Kuo, M. (2007). How does an online game based learning environment promote students'

intrinsic motivation for learning natural science and how does it affect their learning

outcomes? *Digital Game and Intelligent Toy Enhanced Learning*.

doi:10.1109/DIGITEL.2007.28

Li, Q., & Ma, X. (2010). A meta-analysis of the effects of computer technology on school

    students' mathematics learning. *Educational Psychology Review, 22*(3), 215-243.

    doi:10.1007/s10648-010-9125-8

Liang, J., Heckman, P. E., & Abedi, J. (2012). What do the California standards test results

    reveal about the movement toward eighth-grade algebra for all? *Educational Evaluation and*

    Policy Analysis, 34(3), 328-343. doi:10.3102/0162373712443307

Linnenbrink-Garcia, L., Durik, A. M., Conley, A. M., Barron, K. E., Tauer, J. M., Karabenick, S.

    A., & Harackiewicz, J. M. (2010). Measuring situational interest in academic domains.

    Educational and Psychological Measurement, 70(4), 647-671.

    doi:10.1177/0013164409355699

Loveless, T. (2008, September). *The misplaced math student: Lost in eighth-grade algebra*. The

    Brookings Institution. Retrieved from Social Science Premium Collection:

    http://search.proquest.com/docview/1820777318

Malone, T. W. (1980). *What makes things fun to learn? a study of intrinsically motivating*

    computer games Available from Dissertations & Theses @ Stanford University. Retrieved

Meyer, D. (2010). *Math class needs a makeover* [Video file]. Retrieved from

    https://www.ted.com/talks/dan_meyer_math_curriculum_makeover?utm_campaign=tedspre

    ad&utm_medium=referral&utm_source=tedcomshare

Michael, D., & Chen, S. (2006). *Serious games*. Mason, OH: Course Technology.

Michigan State University (2018). Connected mathematics: A research overview. Retrieved from https://connectedmath.msu.edu/_connectedMath/assets/File/research/

Mishra, J., Anguera, J., & Gazzaley, A. (2016). Video games for neuro-cognitive optimization. *Neuron, 90*(2), 214-218. doi:10.1016/j.neuron.2016.04.010

Mitchell, M. (1993). Situational interest. *Journal of Educational Psychology, 85*(3), 424-436. doi:10.1037/0022-0663.85.3.424

Mondéjar, T., Hervás, R., Johnson, E., Gutierrez, C., & Latorre, J. M. (2016). Correlation between videogame mechanics and executive functions through EEG analysis. *Journal of Biomedical Informatics, 63*, 131-140. doi:10.1016/j.jbi.2016.08.006

Nachimuthu, K., & Vijayakumari, G. (2011). Role of educational games improves meaningful learning. *I-Manager's Journal of Educational Technology, 8*(2), 25. Retrieved from http://search.proquest.com/docview/1473901505

National Council for Teachers of Mathematics. (2008). *Principles and standards for school mathematics*. Reston, VA: Author.

National Science Foundation, and NASA. (2008). Fostering *learning in the networked world: The cyberlearning opportunity and challenge. A 21st century agenda for the National Science Foundation.* Hampton: NASA/Langley Research Center. Retrieved from https://www.nsf.gov/pubs/2008/nsf08204/nsf08204.pdf

Nicol, A. (1990). Interfaces for learning: What do good teachers know that we don't. *The art of human computer interface design* (pp. 113-122). Reading, MA: Addison-Wesley.

Nokes, T. (2004). Testing three theories of knowledge transfer. *Proceedings of the Cognitive Science Society, 26*(26), 1029-1034.

Nomi, T., & Allensworth, E. (2009). "Double-dose" algebra as an alternative strategy to remediation: Effects on students' academic outcomes. *Journal of Research on Educational Effectiveness, 2*(2), 111. doi:10.1080/19345740802676739

Oregon Department of Education, Portland Public School District (2016). *School: Sunnyside environmental school.* Retrieved from https://www.ode.state.or.us/data/reportcard/reports.aspx

Palfrey, J., & Gasser, U. (2008). *Bone digital.* Philadelphia, PA: Basic Books.

Panoutsopoulos, H., & Sampson, D. G. (2012). A study on exploiting commercial digital games into school context. *Journal of Educational Technology & Society, 15*(1), 15-27.

Papastergiou, M. (2009). Digital game-based learning in high school computer science education: Impact on educational effectiveness and student motivation. *Computers & Education, 52*(1), 1-12. doi:10.1016/j.compedu.2008.06.004

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas* (2nd ed.). Brighton, England: Harvester Wheatsheaf.

Plass, J. L., O'Keefe, P. A., Homer, B. D., Case, J., Hayward, E. O., Stein, M., & Perlin, K. (2013). The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation. *Journal of Educational Psychology, 105*(4), 1050-1066. doi:10.1037/a0032688

Polya, G. (1963). On learning, teaching and learning teaching. *American Mathematics Monthly, 70*, 605-619.

Prensky, M. (2001). Digital natives, digital immigrants, part 1. *On the Horizon, 9*(5), 1-6. doi: 10.1108/10748120110424816

Prensky, M. (2007). *Digital game-based learning*. New York: McGraw-Hill.

Rakes, C. R., Valentine, J. C., McGatha, M. B., & Ronau, R. N. (2010). Methods of instructional improvement in algebra: A systematic review and meta-analysis. *Review of Educational Research, 80*(3), 372. Retrieved from https://search.proquest.com/docview/756977989

Ruiperez-Valiente, J., Munoz-Merino, P., Leony, D., & Kloos, C. (2015). ALAS-KA: A learning analytics extension for better understanding the learning process in the khan academy platform. *Computers in Human Behavior, 47*, 139-148. doi: 10.1016/j.chb.2014.07.002

Rice, J. W. (2007). Assessing higher order thinking in video games. *Journal of Technology and Teacher Education, 15*(1), 87. Retrieved from http://search.proquest.com/docview/200003526

Rideout, V. J., Foehr, U. G., & Roberts, D. F. (2010). *Generation M2: Media in the lives of 8- to 18-year-olds* [electronic version]. Menlo Park, CA: Henry J. Kaiser Family Foundation. Retrieved: http://parlinfo.aph.gov.au/parlInfo/search/summary/summary.w3p;query=Id:%22 library/lcatalog/00161465%22

Rieber, L. P. (1996). Seriously considering play: Designing interactive learning environments based on the blending of micro worlds, simulations, and games. *Educational Technology Research and Development, 44*(2), 43-58. doi:10.1007/BF02300540

Roschelle, J. M., Pea, R. D., Hoadley, C. M., GordinDouglas, N., & Means, B. M. (2000). Changing how and what children learn in school with computer-based technologies. *The Future of Children, 10*(2), 76-101. Retrieved from http://www.jstor.org/stable/1602690

Rosen, L. D. (2010). *Rewired*. New York, N.Y.: Palgrave Macmillan.

Ross, A., & Willson, V. (2012). The effects of representations, constructivist approaches, and engagement on middle school students' algebraic procedure and conceptual understanding. *School Science and Mathematics, 112*(2), 117-128.

Rubens, M. T., Zanto, T. P., Gazzaley, A., & Thangavel, A. (2011). Causal role of the prefrontal cortex in top-down modulation of visual processing and working memory. *Nature Neuroscience, 14*(5), 656-661. doi:10.1038/nn.2773

Salpeter, J. (2003, Oct 1,). 21st century skills: Will our students be prepared? *Technology & Learning, 24*, 17. Retrieved from http://search.proquest.com/docview/212099794

Sanford, K., Starr, L. J., Merkel, L., & Bonsor Kurki, S. (2015). Serious games: Video games for good? *E-Learning and Digital Media, 12*(1), 90-106. doi:10.1177/2042753014558380

Schaffhauser, D. (2016, January). Report: Education tech spending on the rise. *The Journal*. Retrieved from https://thejournal.com/Articles/2016/01/19/Report-Education-Tech-Spending-on-the-Rise.aspx?p=1

Schunk, D. H. (1990). Introduction to the special section on motivation and efficacy. *Journal of Educational Psychology*, *82*(1), 3-6. doi: 10.1037/h0092681

Shaffer, D. W., Squire, K. R., Halverson, R., & Gee, J. P. (2004). Video games and the future of learning. Retrieved from http://www.educause.edu/Resources/VideoGamesandtheFutureofLearni/153925

Shin, N., Sutherland, L. M., Norris, C. A., & Soloway, E. (2012). Effects of game technology on elementary student learning in mathematics. *British Journal of Educational Technology, 43*(4), 540-560. doi:10.1111/j.1467-8535.2011.01197.x

Silver, E. A. (2000). Improving mathematics teaching and learning: How can principles and standards help? *Mathematics Teaching in the Middle School, 6*(1), 20. Retrieved from https://search.proquest.com/docview/231299646

Squire, K. (2002). Cultural framing of computer/video games. *International Journal of Computer Game Research, 2*(1). doi:10.1007/978-94-007-2777-9

Squire, K. (2005). Changing the game: What happens when video games enter the classroom? *Innovate: Journal of Online Education, 1*(6). Retrieved from https://refworks.proquest.com/library/read/doc:595581a0e4b0a75b62f4f94f/

Star, J. R. (2005). Reconceptualizing procedural knowledge. *Journal for Research in Mathematics Education, 36*(5), 404-411. Retrieved from http://www.jstor.org/stable/30034943

Star, J. R., and Stylianides, G.J. (2013). Procedural and conceptual knowledge: Exploring the

    gap between knowledge type and knowledge quality. *Canadian Journal of Science,*

    Mathematics, and Technology Education, *13*(2), 169-181.

    doi:10.1080/14926156.2013.784828

Vogel, C. (2008, May). Algebra: Changing the equation: Support programs decrease math

    anxiety and help students succeed. *District Administration, 44*, 34-40. Retrieved from

    https://refworks.proquest.com/print/doc:59879648e4b096698eb0e506/

Voskoglou, M. (2012). Recent research advances in problem-solving. *International Journal of*

    Mathematics, Game Theory, and Algebra, 21(2/3), 181. Retrieved from

    http://search.proquest.com/docview/1713726142

Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological processes*.

    Cumberland: Harvard University Press. Retrieved from http://replaceme/ebraryid=10698709

Wang, H., Tsai, S., Chou, C., & Hung, H. (2010). *The study of motivation and reasoning*

    faculties of game-based learning in elementary school students. Paper presented at the 2nd

    International Conference on Education Technology and Computer (ICETC). Abstract

    retrieved from doi:10.1109/ICETC.2010.5529554

Wendt, S., Rice, J. (2013). *Evaluation of ST math in the Los Angeles Unified School District.*

    Retrieved from the MIND Research Institute website:

    https://www.mindresearch.org/results/research/

Weppel, S., Bishop, M., & Munoz-Avila, H. (2012). The design of scaffolding in game-based learning: A formative evaluation. *Journal of Interactive Learning Research, 23*(4), 361. Retrieved from https://search.proquest.com/docview/1095525810

West, D. M. (2011). *Using technology to personalize learning and assess students in real-time*. Retrieved from http://search.credoreference.com/content/entry/heliconcwh/6_october_2011

Appendix A

The Student Motivation Survey (SMS)

Name: _____

Mark (X) one answer for each question, using these answers:

1. Strongly agree

2. Agree

3. neutral

4. disagree

5. strongly disagree

Statements	1	2	3	4	5
1. I like hard, challenging math problems.					
2. If the teacher discusses something interesting I might look for more information.					
3. Our class is fun.					
4. I solve math problems because I have to.					
5. I like it when questions make me think.					
6. I am good at math.					
7. This year I like math.					
8. I like to research new things on the internet.					
9. My friends tell me I'm good at math.					
10. I like being the best at math.					
11. I look forward to finding out my math grade.					
12. I actually look forward to going to math class this year.					
13. I always solve problems exactly as the teacher wants it.					
14. I like solving puzzles.					
15. My parents often tell me what a good job I'm doing in math.					
16. Finishing every math assignment is very important to me.					
17. I like to help my friends with their math.					
18. I try to get more answers right than my friends.					
19. I am willing to work hard to demonstrate reasoning skills.					
20. It is very important to me to be good at math.					

Appendix B

Name _____

Simplify or solve.   3. $8y = 56$

1. $6y - 4 + y$ 4. $6p + 22 = 10$

2. $z + 6 = -5$ 5. $5 - 4y + y - 1 = -23$

6.   **LUNCH** You bought 3 pieces of pizza that cost x dollars each, a salad for $3, and a drink for $1. Write an expression in simplest form that represents the total amount

7.   **WEATHER** The temperature fell 16° between noon and 3:00 P.M. At 3:00, the temperature was 3°F. Write an equation to determine the temperature at noon.

8.   **SPORTS** A coach buys a uniform and a basketball for each of the 15 players on the team. Each basketball costs $9.40. The coach spends a total of $420 for uniforms and basketballs. Write an equation that models the situation with u, the cost of one uniform.

9.   Select the expression equivalent to:

$$(3x + 2) + (-6x + 3)$$

A. $-3x+5$

B. $3x+5$

C. $9x+5$

D. $-9x+5$

10.   Select **all** expressions that are equivalent to:

$$3x + 5(-4x + 12) - (x - 3)$$

A. $-18x + 63$

B. $18x - 63$

C. $3x - 20x + 60 - x + 3$

D. $3x + 20x + 60 - x - 3$

Appendix C

Name _____

1. You are piloting a boat that is on route to a sunken vessel off of the Oregon coast. The current line of travel (according to the Captain's Log) has you traveling along the linear path of:

$$y = 2x + 6$$

The dive map shows that you need to plot a course to intercept the site that is at location

(3, 9).

Will you reach the site on your current course? Show all of your work.

2. You just finished exploring a dive site and wish to move to a new location along the path of :

$$y = 3x - 3$$

You lost half of the mapped location! You know that the west coordinate (y) was 6. What is the north (x) coordinate?

Appendix D

STEM survey - Khan group

This survey will give me feedback on our 1st STEM unit for students that participated in the Khan Academy+ group

1.
Email address *

_____

2.
1. Indicate how much you agree or disagree with the following statement: "I looked forward to the days that we used computers as part of the STEM class."
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly Agree

3.
2. How would you rate your experience with the Khan Academy activities?
Mark only one oval.

	1	2	3	4	5	
Strongly Negative	◯	◯	◯	◯	◯	Strongly Positive

4.
3. How would you rate your experience with the Desmos activities?
Mark only one oval.

	1	2	3	4	5	
Strongly Negative	◯	◯	◯	◯	◯	Strongly Positive

5.
4. Compared to other lessons, how much math do you think that you learned by using interactive simulations (Khan Academy and Desmos)?
Mark only one oval.

	1	2	3	4	5	
A lot less	◯	◯	◯	◯	◯	A lot more

6. **5. Based on your answer to #4, can you explain your answer, and provide an example?**

_____

_____

_____

_____

_____

7.
   6. Indicate how much you agree or disagree with the following statement: "Video games and computer simulations (Desmos) help me to learn."

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

8.
   7. Is there anything else that you would like to tell me about using Khan Academy or Desmos to learn math?

_____

_____

_____

_____

_____

Appendix E

STEM survey - Dragonbox group

This survey will give me feedback on our 1st STEM unit for students that participated in the Dragonbox Algebra group

*Required

1.

Email address *

_____

2.

1. Indicate how much you agree or disagree with the following statement: "I looked forward to the days that we used computers as part of the STEM class." *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly Agree

3.

2. How would you rate your experience with the Dragonbox Algebra game?
Mark only one oval.

	1	2	3	4	5	
Strongly Negative	◯	◯	◯	◯	◯	Strongly Positive

4.

3. Compared to other lessons, how much math do you think that you learned by using interactive simulations (Dragonbox)?
Mark only one oval.

	1	2	3	4	5	
A lot less	◯	◯	◯	◯	◯	A lot more

5.

4. Based on your answer to #3, can you explain your answer, and provide an example?

_____

6.

5. Indicate how much you agree or disagree with the following statement: "Video games and computer simulations (Dragonbox) help me to learn."
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree