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A case study exploring the effects of using an integrative STEM curriculum on eighth grade students' performance and engagement in the mathematics classroom

Norman Robinson

ACCEPTANCE

This dissertation, A CASE STUDY EXPLORING THE EFFECTS OF USING AN INTEGRATIVE STEM CURRICULUM ON EIGHTH GRADE STUDENTS' PERFORMANCE AND ENGAGEMENT IN THE MATHEMATICS CLASSROOM, by NORMAN F. ROBINSON III, was prepared under the direction of the candidate's Dissertation Advisory Committee. It is accepted by the committee members in partial fulfillment of the requirements for the degree, Doctor of Philosophy, in the College of Education and Human Development, Georgia State University.

The Dissertation Advisory Committee and the student's Department Chairperson, as representatives of the faculty, certify that this dissertation has met all standards of excellence and scholarship as determined by the faculty.

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A case study exploring the effects of using an integrative STEM curriculum on eighth grade students' performance and engagement in the mathematics classroom

by

Norman F. Robinson III

Under the Direction of Dr. Iman Chahine

ABSTRACT

To address the need to improve student achievement in STEM disciplines, effort has been made to develop a new of tools for STEM education (Bybee, 2013). The Robotics and Engineering Design Curriculum (REDC) provides students an opportunity to develop systems thinking abilities while integrating science and mathematics concepts. Using an exploratory case study approach within a situated cognition framework, this study examines the effects of using REDC on 54 eighth grade students' performance and engagement during 5-week integrative STEM instruction in the mathematics and science class. Situational factors that contribute to students' success in learning STEM concepts are also examined.

This study employed mixed-methods techniques. The quantitative data collected included pre/post achievement tests and pre/post motivation and engagement scale (MES) surveys. Quantitative data analysis included reliability analyses and paired sample *t*-tests. The results of the reliability analyses for the achievement test and MES survey report acceptable Cronbach's alpha (.843 and .787, respectively). Qualitative data collected included semi-structured interviews, field notes and student artifacts (engineering notebook and printed prototypes). Qualitative data analysis used coding procedures suggested by Saldana (2012) where patterns were identified and grouped to allow the emergence of themes. Collectively, the data was triangulated to support six emerging themes. The emerging themes regarding the effect of using the curriculum are as follows: (1) the developing anthropomorphic relationship with the robot enhances engagement, (2) engagement is impacted by purposeful and intentional physical action, and (3) purposeful collaboration promotes engagement through the construction of meaning and interaction. Three themes emerged identifying factors that contribute to success: (1) learning environment must have transformative learning potential, (2) learning experiences underpinned by design thinking contribute to success and (3) contextual relevance is enhanced when students have the freedom to their design learning journey. This study addresses the need for research into the implementation of 3-D design and manufacturing in the middle school classroom.

Bybee, R. W. (2013). The case for STEM education: Challenges and opportunities. National Science Teachers Association.

Saldaña, J. (2012). The coding manual for qualitative researchers (No. 14). Los Angeles, Ca: Sage.

INDEX WORDS: Integrative STEM, Engineering Design Cycle, Project Based Learning

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DEDICATION

This work is dedicated to my mother, Gloria Scott Robinson and my grandmother, Doretha S. Lee. Thank you for believing in me, pushing me, supporting me and loving me. I pray you are smiling down from heaven. I miss you and love you.

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To my wife, thank you for your unwavering understanding and support in helping me achieve this dream. This could not have happened without you, and I wouldn't want it to anyway! You are truly my answer from God. I love you!

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Introduction

Global positioning has become an increasing concern in the United States. The country that holds the position of leadership globally influences world economy and motivates policy (Williams, 2011). During most of the time since the industrial age, the United States has held this position of leadership and has been a major competitor in the worldwide arena. With the turn of the new century, this position has slowly become tenuous and the ranking is in a period of decline (Atkinson, 2010). The urgency is magnified by the emergence of other countries advancing in innovation and manufacturing. These advancements provide fuel for economic growth and global position. With science, technology, engineering and mathematics driving a major portion of technological innovation, the nation's focus has shifted to policies that address this matter.

Wissehr, Concannon and Barrow (2011) define the period during the 1950's to 1970's as the Sputnik Era. The Russian launch of the Sputnik satellite inspired America to engage in the movement of developing a mathematical and scientific literate society. This movement was in response to Russia's perceived leapfrog advancement over the United States. This era served as a trumpet call to educate citizens with the intent of maintaining technological superiority. Technology advancements motivate a healthy and growing economy. Innovation inspires the improvement or the creation of new products, processes and services. Atkinson (2010) claims that it is these technological innovations that are driving forces behind economic growth and competitiveness. Since this era, the prevalent perception is that the country is in decline technologically. A fundamental question that has arisen asks what is needed to develop and maintain economic stability and develop the 21st century workforce. Zhao (2010) states that the risk of losing the highly regarded leadership position is due in part to the poor workforce development. A properly trained workforce is integral to grow and sustain an economy driven by technology and innovation. These factors have motivated many to ask if we are currently in this generation's Sputnik Era.

During this time, students have become disengaged in the mathematics and science classrooms. Balfanz, Herzog and Iver (2007) assert that middle school students in the United States are falling behind especially in urban communities. Many factors have attributed to student disengagement and performance decline in the middle schools. Kieffer, Marinell and Neugebauer (2014) cite curricular demands and changing school environment as being some of the factors for the decline. With the deterioration evident, the call for reform addressing student performance and engagement has been made (PCAST, 2010).

Statement of the Problem

The problem addressed in this study examined the need for middle school students to become STEM (Science, Technology, Engineering and Mathematics) literate, the lack of defined focus for STEM integration, and the decline of student performance and engagement in the mathematics classroom. Following is a discussion of each aspect of the problem.

Need for STEM Literacy

Bybee (2013) states that many of the jobs and careers needed to support innovation are currently and will be rooted in STEM disciplines. The President's Council of Advisors on Science and Technology, PCAST (2010), states that the workforce produced in the current education system has had their creativity dulled and stifled. At the same time, students have not performed well in science and mathematics nationally. Stephens (2014) states that internationally, United States 15-year-old students are ranked below average on the Programme for International Student Assessment (PISA) given in 2012. The assessment measured the acquired skills and knowledge that are essential for participation in modern technological societies. Students in America showed weaknesses in performing higher-level cognitive tasks such as real world problem solving. As a result, the students are inadequately prepared for success and prosperity in the workforce. Atkinson (2010) states that the number of STEM degrees earned has been outpaced and at times doubled by Non-STEM degrees. He also maintains that the low number of American students going into to STEM fields poses risks to the economy growth.

PCAST (2010) claims that STEM job and career growth will outpace the number of educated and trained professionals needed for these occupations. Roberts (2012) claims that the United States is ranked 18^{th} among industrialized nations of students graduating and the country is falling in graduation rates. Bybee (2013) asserts that for the United States to maintain global competitiveness a greater effort must be made to produce STEM literate students to form a 21^{st} century workforce. These students will be equipped with fundamental concepts and knowledge in the areas of STEM. Along with being STEM literate, the students will have critical problem-framing and solving skills. However, Roberts (2012) states that today’s educational system will not meet the demands to produce STEM literate members of the society thus causing a shortage of workers to regain the leadership position globally. Even though there has been an increase in graduation rates as reported by the Department of Education as reported by Camera (2015), the celebration has been subdued with the evidence of misreporting and the fact that students’ mathematics and science scores dropped for the first time during the past decade. Under the traditional methods of instruction, students are not being attracted to careers or majors in STEM.

With innovation and creativity being influential skills overlooked in the classroom today, we are manifesting a generation of students that have a strong disinterest in STEM related fields and disciplines.

Lack of Defined Focus

STEM education is seen as a vehicle in which the U.S. can educate and train a 21st century workforce. Bybee (2010) describes that there still exists a wide gap of misunderstanding of STEM education. STEM education from the onset of its inception was considered a basic label for anything that related to science, technology, engineering and mathematics. Although, the focus was heavily placed on science and mathematics, the manner of instruction varied. Presently, Brown, Brown, Reardon, and Merrill (2011) state that there has been a lack of understanding of what STEM education is in schools today.

Bybee (2013) claims that many perspectives of STEM pervade the educational landscape. The absence of focus has created many definitions. For example, he describes the idea of STEM education starting with instruction facilitated in separated discipline silos. This approach has a focus on either mathematics or science. This approach is characterized by an emphasis on both subjects but still contained in their separate silo. Another approach shows that STEM could possibly mean the incorporation of two or more subjects anchored by one subject. For example, science teachers incorporate technology and engineering in lessons such as egg drop or drag racing car activities. Another example highlights the efforts of mathematics teachers using biology and art to describe characteristics of nature through sequences.

Another perception of STEM education is the combination of two or more disciplines into one instructional course. This combination is currently present in engineering and technology classes offered as electives just like band or orchestra. The more complicated version of STEM education has all of the disciplines combined to form a stand-alone course. With many forms and perceptions of STEM education, there is a need for forming a foundation that is present in the described characterizations. Bybee (2010) claims that STEM education should be the place where students solve problems in context using non-routine problem solving skills, self management, and self development. He describes an environment where a student participates socially developing complex communication to use systems thinking to solve real world challenges. At all school levels, with an emphasis on middle school, the need to bring STEM into focus is evident. Saxton, Burns, Holveck, Kelley, Prince, Rigelman and Skinner (2014) contend that a focused perspective of STEM aids the design of instruction and assessment.

Student Engagement and Performance

Students in the United States have lost interest in science and mathematics. Chen (2015) claims that this problem has plagued education for generations. Many reasons have been attributed to the disengagement of students. For example, the use of lecturing as a primary mode of instruction to a teacher's inability to include all students in the instructional activities have been identified as reasons why students disconnect from the learning process. Another glaring reason for student disengagement is the continued teaching of skills and practices that do not translate to relevant material for the 21st century workplace (Atkinson, 2010). As we move towards a more technologically advanced world, we are slow to educate and develop skills needed for the 21st century workplace.

Bybee (2013) also informs that after a decade of education reform, we still have a situation where students in the United States are below average proficiency. There is a correlation to the student's proficiency to the quality of mathematics and science instruction that they receive. With a consistent call for students to perform with abilities that are characterized by innovation and higher order problem solving, there is a place to incorporate activities that include design thinking and engineering. Design thinking develops creative confidence through hands on projects and engineering allows for students to use the creativity to solve real life problems (Kwek, 2011).

Purpose and Research Questions

The purpose of this study was to investigate and describe the effects of using project-based integrative STEM modules on eighth grade students' performance and engagement in a unit on functions in Algebra. The study was guided by the following research questions:

1. What is the effect of using project-based, integrative STEM modules on 8^{th} grade student performance and engagement in learning a unit on linear functions? More specifically, to what extent are grade 8 students able to make connections between linear functions and its applications?
2. What STEM-related situational factors contribute to 8th grade students' success in learning using project based, integrative STEM modules?

Significance of the Study

The study is significant for many reasons. First, there is a need to develop STEM literate students entering the workforce. Secondly, there is a demand for the identification of strategies and practices that narrow the definition of integrative STEM education. Lastly, there is a lack of reporting and communication of the effects of student participation in integrative STEM activities on their performance and engagement.

The call for a STEM proficient and prepared society requires the improvement of STEM education. The focus is on the preparation of all students. Due to the complexity of the learning environment, there is a question of determining viable processes to investigate, study and communicate the integrative STEM teaching and learning experience present in the model. Honey (2014) reports the recommendation posed by the National Academy of Sciences, which calls for the exploration of the curriculum and pedagogical interventions in detail with attention focused on the nature of integration and how it is supported.

This study examined how the integrative nature of the learning experiences support the development of knowledge and practices that form the foundation of 21st century workplace skills. By exploring the factors that lead to performance and engagement, instructional practices are identified and highlighted for use in other areas of instruction. Aspects of the learning environment can be replicated to motivate the development of critical thinking skills. Ultimately, strategies are identified that promote student interest and proficiency in STEM with the purpose of guiding them to become STEM literate.

Theoretically, the study examined the social nature of learning in the context of real world situations. Honey (2014) asserts that the design of integrative STEM should be based in the interactions of students, teachers and the community. This study was built upon the social nature of learning foundation and provided a blueprint to how one engages in integrative STEM problem solving. By exploring the framework of situatedness, examples were given to show how students engage in activities where core discipline content is applied and transferred to similar situations.

Theoretical Framework

Xaviers's School for Gifted Youngsters is a fictional school for Marvel's X-Men. Along with teaching subjects like English and math, Professor Charles Xavier primarily trains the young students with extraordinary skills and abilities to control their powers with the intent of fostering a friendly human-mutant relationship. Professor X recognizes their gifts and talents and wants to take them to higher measures of success and performance. He uses various instructional strategies and lessons to facilitate the growth of each young mutant's unique gift. The professor created a school to prepare them for life and the challenges they will have to endure. He realized that their development would be benefited from learning as a team and not individually. Thus he tailored their learning experiences to be done collaboratively. Their primary classroom was a place called the Danger Room. Here he designed simulations that replicated situations they would face as members of this unique team. The simulations were intricate and detailed. They resembled the ill structured problems and situations they would face in the real world. Thus, the situation represented the actual problem in context, authenticity and danger. The journey of solving these challenges could only be done as a team. Only as a team, could they succeed and prepare themselves for other challenges that would come before them as they protected earth against enemies here and beyond.

The above-mentioned description is from *The Uncanny X-men* comic from 1981. The main learning environment that is described is called the Danger Room (Trushell, 2004). The room is designed to present the situations of rescue and combat to a team of young mutants in preparation for their journey as superheroes. Professor X guides them through exercises from the control room located at the top of the room. Extensive modeling programs allow for training in realistic and authentic environments from outer space to the depths of an ocean. Projectiles are hurled at them to sharpen skills and techniques. The team of mutants collaborate and negotiate with themselves in the best manner to overcome each challenge presented to them in the Danger Room. By using their unique gifts and resources, the team comes together as a community to achieve success and develop lifesaving skills for preservation and protection of Earth. Learning by doing in context is an overarching theme present in the Danger Room.

The description for the Danger Room in the above paragraphs could also be painting a picture of a middle school classroom. The students in the classroom can be immersed in an authentic real world challenge, for example developing exoskeleton robotic prosthesis to aid diabetic patients with the amputation of a limb. As often displayed in the real world of science and engineering, the students would collaborate in design teams to find solutions. These students would use relevant tools that are used by those in industry in the same manner as those would in professional settings. Just as Professor X deems to immerse his young mutant learners in activities that foster the development of useful knowledge, the middle school classroom can be designed to afford relevant tasks that are interestingly meaningful and promote learning of the concepts involved. Professor X believed that with the help and the aid of others in their group, they are able to utilize and develop the tools needed to achieve a successful mission. Stein (1998) describes a classroom where students work together with experts to novices to develop meaning and solve problems. Even though students come with different unique talents and abilities, when they are joined together to solve the problems of the class, they can develop skills that go beyond and be successful throughout life. Both of the examples, Professor X's Danger Room and the middle school classroom, are spaces that demonstrate the tenets of situated cognition.

This examination of the theoretical framework is divided into four parts. In part 1, I will discuss and examine the definition of situated cognition theory. The learning processes that make up situated cognition, communities of practice, legitimate peripheral participation and cognitive apprenticeship, will be discussed. An analysis of the basic tenets of situated cognition will solidify the theoretical framework developed.

In part 2, I will explore the historical development of situated cognition. A review of the precedents from which the development of situated cognition originated. Some of the pioneers and their theories will be inspected to discuss their influence on the framework. The foundation of “situatedness” will be explored.

Part 3 will focus on the ontological and epistemological underpinnings. This section will discuss the definition of what knowledge is in relation to situated cognition to understand how attaining knowledge takes place. Finally, part 4 will investigate situated cognition in the instruction of STEM education. The process of designing learning experiences on the foundation of investigating the world in an authentic manner through real world problem solving will be discussed. Investigating the learning processes of situated cognition will provide insight to how engagement and proficiency is impacted.

Situated Cognition Defined

Lave (1988) states that situated cognition is a theory where an individual’s cognitive activity cannot be isolated from the social context from which it occurs. Brown, Collins, and Duguid (1989) further develops Lave’s definition of situated cognition as the presupposition that learning and knowledge acquisition is embedded in an authentic context and activity within the culture it resides. Lave (1988) defines authentic activities as purposeful, meaningful actions but ordinary to the practices of the culture. Lave and Wenger (1991) believe that learning is situated in the activity in which it is taking place and is integral to a culture’s generative social practices. From this definition the notion of learning can be understood to be done by all in the community in the way or manner that the activities are done in real life. Stein (1998) adds to the definition that the process of learning occurs as a result of relationships established between the learners, the activities and the social organization of the communities involved. Brown et al. (1989) state that the knowledge acquired as a result of these relationships and the associated concepts are like tools and resources of the culture. These tools and resources can only be understood through expert guidance and use. The conceptual knowledge acquired is no longer seen as a standalone acquisition of facts. Knowledge becomes a tool that is applicable, useful and robust. Through active use of the tools, participants will deepen their understanding. Utilization of the tool will be developed much further than any abstract or explicit rules that may accompany the tool. The use of the tool will aid in the development of its understanding. The understanding will change and grow as expertise is developed. Just as the understanding of the tools change, the participants' roles in this process will develop and change over time (Brown et al., 1989). Participants will be afforded the opportunity to develop and adapt. As Brown et al. (1989) asserts, participants become enculturated in the social structure of the situation. Figure 1 below is a depiction of the interaction with the contexts that have been previously characterized.

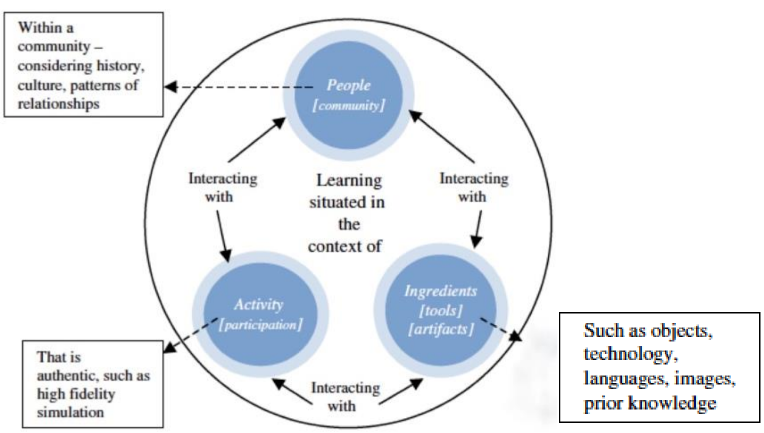


Figure 1. Situated Cognition Theoretical Framework. Adapted from "Situated cognition: A learning framework to support and guide high-fidelity simulation," by J.B. Paige and B.J. Daley, 2009, *Clinical Simulation in Nursing*, p. 99.

Varela, Thompson, and Rosch (1991) extend the theory stating that being situated lends to an understanding that cognition depends on bodily experience with its environment. This perspective brings into view that cognition requires the immersion of the body's sensorimotor capabilities. The connection between mind and body is characterized as the embodiment of the mind. Robbins (2009) claims that the embodiment of the mind allows for sensory perception of the environment as inputs and motor activity as outputs. Varela et al. (1991) further describe this relationship as physical, temporal and functional. As a result of the characterization of the relationship, the learner interacts with its environment to form reality and develop reason. From this claim, Robbins (2009) concludes that thought is empty without the embodiment of the mind. Wilson (2002) further describes the embodiment of the mind as being on-line or off-line. On-line embodiment involves the body in a literal sense. Robbins (2009) describes the on-line interaction between the mind and body as a dynamic relationship involving motor nerves, sense organs and limbs. Wilson (2002) describes off-line embodiment as the condition where cognition occurs through memory and mental imagery.

All of the characterizations of situated cognition lead to a focus on the social structures and learning processes in the environment. The social structures and learning processes are communities of practice, legitimate peripheral participation and cognitive apprenticeship. Figure 2 below depicts their relationship with each other. At the center is the situated context. Lave and Wenger (1991) describe learning as being situated in a community of practice and represents development from peripheral activity to more expert participation where learning can be seen as a form of apprenticeship. Students immersed in the situated context enter in as a newcomer to a community. As the community engages in the context they are enabled to acquire, develop and use cognitive tools germane to the authentic activity. The learning is enhanced and promotes the social construction of knowledge. Community of practice, legitimate peripheral participation and cognitive apprenticeship will be a described to give further insight to the theory of situated cognition.

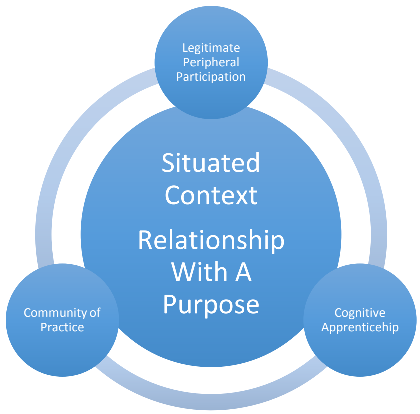


Figure 2. Situated Cognition Concept Map.

Community of Practice

According to Lave and Wenger (1991), a community of practice is a group of people who share skills, inquiries, set of problems, or interests individually and as a group. In the community, Hung (2001) argues that the members are connected socially by beliefs and ways of thinking. As newcomers become engaged, they enter with little knowledge of the norms and practices of the community. Learners begin to move from one level to another engaging in a process of collective learning in a shared space where the problem or challenge is presented. The members develop shared resources and tools that will aid them in problem solving. Lave and Wenger (1991) inform us that this results in the formation of shared practices. These shared practices can be communicated explicitly or not depending on the level they are used and communicated. For example, in programming the code for a robot to perform a series of tasks, certain strategies may be assumed and communicated as standard. Programming the motion of a robot to move linearly is an example where strategies can be assumed. It may be assumed, depending on the engineering of the robot, that motion will incorporate the use of two motors or one depending on design. Another example where other strategies are constructed explicitly would be the determination of the best path to find a location for the deployment of solar stations for energy storage and consumption. Brown et al. (1989) argue that these characteristics of domain, membership and practice form the foundation of a community of practice. The domain refers to the commonality of interest amongst the community or membership. The practice is the set of resources, experiences and tools that the membership uses for problem-solving.

Winbourne (2010) further characterizes a community of practice as participation in identity formation. Identity is formed in a community of practice by creating an apprentice/master scale structure. The learner, by identifying their place on this scale, is informed of their manner of discourse and behavior. A community of practice, as argued by Winbourne (2010), is described as all of the participants actively engaging in the activity of the practice that is constituted by the participants. Wenger (1998) provided the foundation declaring that learning is central to the human identity. The construction of identity through the social practices contributes to the learning process. The individuals in this process participate to form the community's shared identity.

Aspects of interest to a community include the manner of how people are connected to the situation or context in which they are connected. Wenger (1998) classifies this interaction as a relationship with a purpose (Figure 2). This relationship distinguishes itself from other relationships that are created for reasons outside of a shared purpose. Carlisle (2002) expounds on another aspect of interest, which is the use of the community's tools that are used to stimulate learning and generate new knowledge. The activities that afford the participation in the practices of the community allows for a pathway to shared understanding and discarding of knowledge that is not used.

Legitimate Peripheral Participation

Legitimate peripheral participation, as coined by Lave and Wenger (1991), describes how newcomers move from a beginner to an experienced member and from experienced member to a veteran in a community of practice. Legitimate peripheral participation is characterized by the relationship between the beginners and the veterans with regards to the activities, discourse and products of the culture. Hudson (2010) extends the premise that the process of co-participation is integral to learning, as opposed to learning within the heads of individuals. Lave and Wenger (1998) further state that novices enter this process by doing "peripheral" activity. They describe peripheral activity as engagement at the lowest level or residing on the fringe with the least amount of participation. As students progress through the processes, they may assume more than one role. For example, in some engineering learning experiences students may come with limited knowledge of designing and manufacturing prototypes, but have developed problem solving skills. Students may engage by observing or offering comments from the "outskirts" of the process. Over time the students will take on more central responsibilities. This can be seen in the example of the student using 3-D design software then moving to a place where the designs are used to manufacture prototypes for testing and data collection. This process is tailored towards the student's inquiry and ability. The student can be an expert at a lower level but a novice at a higher level. The student moves though this progression at different stages and times during their membership in the community. The student is motivated to learn due to their need to gain more knowledge. The movement continues until the student performs at their highest level and disengages from the community.

Cognitive Apprenticeship

Brown et al. (1989) developed the model of cognitive apprenticeship which emerged from the theory of situated cognition. Collins, Brown and Holum (1991) state that cognitive apprenticeship is a theory that assumes learning is done socially between learners/experts through observation, modeling and imitation. Learning is a process that is done through experience and facilitated by an expert. As stated earlier, the learning is tied to an activity and context which a novice joins in a community of practice from the periphery. The novice learns in context and culture as an apprentice as they move though the process of legitimate peripheral participation. Thus, Brown et al. (1989) claim that cognitive apprenticeship supports the learner through the acquisition, development and use of cognitive tools during the authentic learning activity.

Collins et al. (1991) describe the traditional model of apprenticeship as the expert showing an apprentice how a task is done. After observations, the apprentice practices certain aspects of the task under the facilitation of the expert. As the apprentice gains proficiency doing the task, the expert turns over more responsibility of the task until he feels that the apprentice has gained the proper skill to complete the task on their own. The traditional model is highlighted by four aspects of learning: modeling, scaffolding, guided practice and coaching.

The bridge from traditional apprenticeship to cognitive apprenticeship involves transitioning methods used that would relate to a classroom learning experience. In a traditional apprenticeship the skills needed to learn a specific task are easily observable. Collins et al. (1991) claim that the students' thinking and problem solving skills need to be made visible so that the teacher can guide and facilitate their development. This action is promoted by collaborative and collective problem solving. Also, as with traditional apprenticeship, the tasks arise out of real world situations. To bridge this idea, Polo (2015) states that cognitive apprenticeship emphasizes that learning should be done in context embedded in real world problems. Finally, traditional apprentices learn skills which are inherent to the task. Schooling expects students to transfer knowledge to different tasks. To bridge this idea to cognitive apprenticeship, diverse situations should be presented that show the common use of skills learned.

Lave and Wenger (1991) further developed the social nature of cognitive apprenticeship describing how learning occurs in partnership with others. Learners develop cognitive processes while interacting within a social context of a community. Hung (2001) points to Vygotskian thought that individuals can learn more through interacting with others than they could do independently. Brown et al. (1989) support the importance of social interaction stating that the learner's engagement with a culture's practices affords them the ability to adapt and assimilate these norms. Smith (2004) shows how this premise forms the foundation of the work in artificial intelligence (AI). The study of how robots are programmed to interact and behave in certain communities to acquire knowledge is an area of interest in this field. The robots are programmed with the ability to assimilate itself into a membership by observing the members' behaviors and practices and adopting them for the purpose of engagement. Cognition moves from being rich with representations and symbols to a self-organizing system with its environment. The robot becomes a socially active component of the community and participates with the formation of resources that are used and are relevant to the context of interest. Smith (2004) claims that knowledge and understanding is distributed socially. Socially shared cognition permits the opportunity for knowledge to be developed for use in a situated activity.

Basic Tenets of Situated Cognition

Lave and Wenger (1988) proposed four basic tenets of situated cognition as a theoretical framework: (1) learning is grounded in the actions of everyday situations, (2) knowledge is acquired “situationally” and transfers only to similar circumstances, (3) social processes influence the way people think, interact and solve problems to attain knowledge, and (4) meaning is made socially and is a product of learning. Brown et al. (1989) argue that the four basic tenets underpin the assumption that learners are participating in actual experiences that are relevant to the content learned. First, learning is a function of the activity, context and culture in which it occurs. It is further explained that the activities involved must represent the same that are peculiar to the culture where meaning and purpose is socially negotiated. For example, the ruler used by a community of newspaper editors to measure copy layout would be different for a community of engineers using a ruler to measure proper placement of support joists. The authenticity of the context, as claimed by Herrington (1995), reflects how the knowledge will be used in real life without fragmenting the problem and counting for real world complexity. Secondly, Choi (1995) claims that the transfer of knowledge is influenced by situational factors and is successful when cognition is anchored in realistic contexts. Real life problem solving is where transfer is most likely to happen. For example, the Boy Scout transferring knowledge of knot tying to storing food tied to a tree out of the reach of animals. The Boy Scout uses his knowledge of knots to make it easy to retrieve the stored food while at the same time keeping it secure. Thirdly, Brown et al. (1998) explain that learners are continuously interacting with the cultural values and norms in the process’s context. As learners engage in authentic contexts, they are applying the process as a means of participating in this social structure. Finally, as a participant of a culture, knowledge is developed as well as a sense of when and how to use it.

Historical Development

Situated cognition has its beginnings in psychology, anthropology, sociology and cognitive science (Gallagher, 2009). The question that drives interest in the phenomenon of learning is how does cognitive development take place and what is its role in learning? Young (2003) states that the emerging perspectives carry the beliefs that the constructivist platform directs the act of meaning making. These emerging perspectives provide the nutrients where the roots of situated cognition are fortified and developed. Several theories provide the path to situated cognition, Lev Vygotsky and John Dewey socio-cultural theory, ecological psychology, everyday cognition and critical theory.

Lev Vygotsky's view of cognitive development differs from the work of Piaget and provides foundation on which situated cognition is constructed. At the heart of his view is the premise that learning is a social experience. This is a key difference between his view and Piaget's view. Piaget believed that development must precede learning. Vygotsky believed that "social learning is likely to precede development (Yilmaz, 2011, p. 207)." Knowledge is an internalization of social activity. Yilmaz (2011) claims that Vygotsky argues that culture plays a key role in cognitive development. The people are important players just as the cultural artifacts and practices. Learners actively engage in all of the interactions between these players to construct knowledge and skill. Subsequently, learning is viewed as the relationship and connection between the individual and the society. This relationship promotes, dictates and regulates the development of cognition. Thus the social experience is bounded by the culture in which it inhabits.

Hung (2001) claims the importance of learning and characterizes it as a social act. The belief is that people construct meanings socially with tools afforded to them or forged by them.

People assemble in a community of practice where they develop the rules and structures that support the community. Freeman (2008) argues that the co-creation of knowledge among the peers promotes active learning. Lehman (2014) claims that working from this perspective, individuals can be seen as meaning makers of the experiences and situations around them. It is from this community that members are engaged in collaboration and problem solving that leads to adaptation, growth and change.

Lave (1991) states that Vygotsky mentioned how the analysis of child's psychological development is centered around two basic tasks, the analysis of the social situation and the analysis of the psychological structures that develop in the social situation. These ideas underpin the concept of Zone Proximal Development (ZPD). Hung (2001) describes Vygotsky's ZPD as the area or distance between what the learner can do by himself with assistance to what the learner can do unaided. The intent is for the educator to provide experiences that are within this zone to enhance and promote learning. As mentioned before, the focus is not only on the end result but also on the process to arriving the end result. Learning in this zone can be scaffolded through the guidance of an expert or in collaboration with other learners. The formation of a community of learners could be created where novices and those who are more developed can interact. During this process the teaching and instruction can be tailored to the individual based on the needs within the culture.

Bredo (1994) argues that John Dewey's assertion that there is no separation between mind and body is another point of foundation for social cognition. Much of the teaching and learning through lecture promotes the idea that learning is done mostly without an interaction between the body and the environment. The situated shift calls for a description of the relationship between the learner and the environment. The relationship is described as the interaction between oneself and its surroundings. The action is described as orchestrated or composed. Therefore, this relationship results in meaningful experiences that are part of the learning process. Bredo (1994) explains how Dewey describes a transactional system that emphasizes the mutual development across abilities. He characterizes it as the space where understanding is obtained through doing. Meaning is co-constructed between the learner and the culture. The community's environment is the place where the development occurs.

Gallagher (2009) says that the systemic view of cognition, which is described as the philosophical, psychological and social development, is influenced by theories and designs from Dewey. Dewey's school explored how learners are able to construct meaning using physical models and representations. The underlying thought is that the facilitation of learning abstract and general concepts can be done through the manipulation of models. Wenger (2014) states that these ideas are found in the theory of constructivism and discussed in the response to Artificial Intelligence's model of knowledge acquisition. The model stated that learning is an active process. Comprehension requires some prior knowledge or experience. A recurring theme is that conceptual understanding is gained by doing. Bredo (1994) contends that Dewey argued against the idea that thinking is a separate activity between perception and action. Dewey states that actively moving and manipulating things shape perception. From this perspective, there is no distinction between mind and body. The moving involved is part of the understanding and meaning making aspect of the process.

The ecological platform of situation cognition gives the foundation of "situatedness." The relationship of the subject and the environment aids in the process of understanding and meaning making. Pick (1992) states that Eleanor Gibson classified affordance as active perceptual learning and development. Learning is based on the perception through the senses based on what is in the environment. Thus, sense is made based on the context of the environment.

Everyday cognition solidifies the framework for situated cognition. Born from the field of cognitive science, the area of investigating every day learning strategies of a certain field is of interest. Henning (2004) espouses that everyday cognitive activity uses the relevant and situational resources and tools, which have been provided, to produce and construct new knowledge. Here the priority is taking a contrived, concerted and sterile experience to a real world authentic study. The real world authentic study is outside of the formal environment and can be viewed as everyday activities. Everyday cognition views of learning of an everyday activity is characterized as developing everyday strategies which are not necessarily taught in a classroom but taught in the environment of the situation. This ideology provides the groundwork for activity being situated. Situatedness is very specific to the activity and authentic in the workings and design of the function.

Ontological Underpinnings

The ontological question aims at addressing the philosophical ideologies of reality in regards to situated cognition. Ontologically, situated cognition does not accept that there is one truth. Stead (2004) argues that there are many truths present based on how it is perceived and situated in relationships. The implications of this assumption reach far and deep in integrative STEM education. The role of the teacher is reshaped from the traditional sage or expert that provides the answer or ultimate truth. The instructor’s role moves from providing and structuring information to the position of guide and co-learner. The teacher now engages as part of the process and facilitates the students through this process.

The view of many truths also leads to the idea that the construction of knowledge is done socially through the interaction and relationships between actors and tools of the community. Scotland (2012) claims that this regard of knowledge construction is done in various ways, but the truth is a consensus formed by the participants in the community. Social construction can include an array of different perspectives. The array includes perspectives from the acknowledgement of how social factors shape interpretations to views on how processes shape the meaning making. The appearance of the interpretations leads to a thorough description that gives insight and depth.

Richards (2001) claims a further assumption that learning is based on context. Human thought and action have a strong relationship to context and are affected by the external characteristics of the contextual surroundings. Cobb (1999) argues that the situated context is traced to the notion of physical location and explains how this view is apparent in example investigations where comparisons are made between learning mathematics in a mathematics class and learning mathematics in a technology class. During the mathematics class, the practices and skills learned may develop a different form of mathematical reasoning than what is used in the technology class. Lave and Wenger (1991) attribute this to the social nature of engaging in the practice in a particular space.

Yilmaz (2011) states that when context is investigated in respect to the learning environment it is assumed the environment uses relevant and authentic tools and resources in the designed environment. It is important to provide situations that utilize skills taught and developed as the learners use them. Lave (1988) states the range of use can be from everyday use by “just plain folks” to those identified as experts. As mentioned before, Yilmaz (2011) states that since the instructor is seen as a guide and a facilitator, teaching is more concerned with the process of learning rather than the instruction of specific skills. Through cognitive development, understanding and knowledge is constructed using the community crafted tools and resources.

Theories of situated cognition argue that the learning space is a complex system and can be viewed from many perspectives. Based on the foundation of theory, an allowance is made to view the world from many historical and cultural contexts. Peters-Burton (2014) argues that an assumption of the integrative STEM approach is that complex critical thinking and problem solving skills are instructed as well as academic knowledge from specific subjects. Thus, there are multiple perspectives that the integrative STEM approach can provide. These multiple perspectives allow for the development of more than discipline content knowledge. Development of critical thinking skills, problem-solving techniques and other soft skills are also addressed in integrative STEM education.

Epistemological Underpinnings

The roots of situated cognition are anchored with social constructivism**.** Young (2004) contends that "Social constructivist, such as Bruner and Vygotsky, recognize that influences on individual construction are derived from and preceded by social relationships" (p.376). Brown et al. (1989) claim that the community and culture craft and develop the tools used in practice by the input made by the individual members of the community. The tools are constructed that resemble the belief structure and values that permeate the culture of the activity. This learning follows a path where the culture influences thinking. As learning progresses, changes in the individual occur in relation to the community or culture. The change is part of the process where the adaptation and evolution can take place and make new rules and tools.

An important aspect to constructivism is that the world and the culture are present from birth. Crotty (1998) argues that there is a pre-existing system in place from birth. There are beliefs and values that have been agreed upon and the acquisition of new knowledge is bound by this system and structure.

With foundations formed in constructivism, situated cognition formed out of behavioral and cognitive science. From the ideology of systems thinking, symbol manipulation enables individuals to describe, express, and create ideas of the environment around them. Seel (2001) holds that situated cognition fundamentally gives the frame that provides meaning making by extracting and organizing information from a given environment. The process gives insight to the relationship and interaction between the individual and the environment. The interaction is defined by the cognitive processes, such as activity, characterized by the interaction between mind, body and the environment.

Now that it is established that the relationship between the individual and the environment produces knowledge, Stead (2004) avows that it is important to establish that knowledge is culturally and socially constructed through discourse. He contributes this to the social nature of knowledge. Learning is done through enculturation. Brown et al. (1989) argue that either consciously or unconsciously humans from an early age assimilate behavior and beliefs systems of social groups. By practicing the culture norms and beliefs, meaning is made by observation or active involvement. Through this involvement, individuals have the chance to develop a base of knowledge and determine relevancy with regards to the construction of meaning. Practicing also gives opportunity to strengthen their culture’s membership. By the immersion of culture, individuals are given access to the conceptual tools and resources used in the activity to strengthen the core of knowledge developed.

Zheng (2010) claims that the research in situated cognition shows that individuals participating in valued social practices through the immersion in authentic activities promote knowledge acquisition. Marra (2014) states, “Knowledge that is anchored, or “situated” in specific contexts is more meaningful, more integrated, better retained and more transferable” (p. 226). Authentic contexts promote engagement from the community and the individuals in the community. Seel (2001) declares that situated, however, differs in understanding among cognitive and educational psychologists. Seel (2001) agrees that the semantics of being situated is thought to be a “product of the internal operations which occur when a learner interacts with a physical and social situation” (p. 406). The learner interacts with the situation by making mental models to simulate the situation in order to make meaning of the situation. A model-based reasoning is promoted where cognitive operations simulate what is happening in real life. As the learner engages cognitively with the environment, the learner develops knowledge. This knowledge is not a separate entity but is in concert with the surroundings it was derived from.

Due to the social nature of knowledge and the process embedded in real authentic contexts, issues of power have to be considered critically. James (2012) declares that knowledge is not only constructed socially but it is subject to the influence of the power structures within the society. Investigation into the power structure seeks to uncover issues of social justice and marginalization. The acquisition of knowledge will be a function of emancipation from a power structure or the modification of how knowledge is acquired. Critical ideology seeks to place value on the making of knowledge. The critical perspective places judgment on reality and makes a statement for what knowledge should be.

Situated Cognition in STEM Learning

Historically STEM educators have discussed and debated the intention and motivation of various models of integration of the four disciplines. From a positivist's point of view, the integration of the four disciplines would not be necessary. James (2012) contends that a positivist epistemological aim is to obtain knowledge that is descriptive and factual. This knowledge has an independent existence without influence from the environment or the person researching it. From the view of situated cognition, the effectiveness of discipline integration can be explained through the lens of obtaining knowledge by doing and investigating the culture where it is occurring. Moye (2014) explains that as STEM education has developed, integration has been unclear and void of a consensus form. The disciplines were taught separately. Instruction was described by the formation of silos where learning experiences that were not connected. It has been recognized that integrative instruction promotes the retention of facts and abstract concepts as well as an understanding of how to apply knowledge and information gained (Wirth, 2008). The application of STEM concepts in one setting is the intent of integrative STEM.

Gomez (2013) affirms the description of integrative STEM as learning concepts using critical thinking and applying problem solving skills. The motivation is to gain understanding how to apply concepts, processes and design thinking in an authentic context. The view of situated cognition provides a lens to understand the intended purpose of STEM education. Learners can obtain an understanding of how things work in the world and how things are interconnected. Moye (2014) maintains that STEM education can enable students to be critical of the world and find answers to solve issues present in society. Peters-Burton (2014) holds that the knowledge gained equips the learner with a better understanding. The learner gains membership in the community and earns the right to the knowledge, resources and tools. Therefore, the process gains more meaning pass the low level of just acquiring facts. Peters-Burton (2014) reminds that the nature of STEM education is underpinned with an assumption that the way of knowing has depths that is not being taught in classrooms today.

Integrative STEM education is characterized as student-centered. Brown et al. (1989) argue that placing the student at the center of instruction places responsibility on the students to be aware of what they know and what they do not know. In light of the shift in responsibility, the integrative STEM model calls for an instructor that has the ability to navigate and facilitate this space. Billiark (2014) states that the model calls for a well-trained instructor equipped with strong social constructivist pedagogical skills and content knowledge. Although the content knowledge is not taught where the expert is pouring the knowledge from their container into their heads. The content knowledge is used as a resource to guide students in a direction to conduct their own research. Brown et al. (1989) state that the teacher is more of a guide and a resource that allows the students to move through the experience regulated by their own inquiry. Here the teacher and student assume the roles of expert/apprentice. Brown et al. (1989) argue that cognitive apprenticeships provide unique experiences where learners are immersed in authentic practices and use tools of social interaction in the process of meaning making. Collins et al. (1991) describe cognitive apprenticeship as people learning from one another through observation, imitation and modeling embedded in an authentic activity. Due to the complexity of the problem, many solutions or strategies can be formulated to show that there is not an absolute process to solve or a singular solution to the problem. In the generation of their own solution, learners become conscious and creative members of the culture and use the tools germane to the culture and the community.

CHAPTER 2

A Review of the Literature

The acronym STEM Education has been catapulted into national focus and is a point of debate among politicians, school personnel, parents and students. The world is evolving into a technology driven society. Bybee (2013) states that many of the jobs and careers needed to support innovation are currently and will be rooted in STEM disciplines. As a result, President Obama has made education reform a high priority in his administration and platform. He commissioned the President's Council of Advisors on Science and Technology (PCAST) to examine the education system. PCAST (2010) released findings outlining the need for better teaching and learning in STEM disciplines. The council made an explicit call for 100,000 well-trained STEM teachers with many added to the field of mathematics. The committee suggested that these teachers should have strong content knowledge and pedagogical skills. Along with the need for better instruction, there is a push to design and create a learning environment that promotes discipline integration and encourages the use of technology. The intended result is to produce a generation of students equipped with critical thinking and problem solving skills. Armed with these skills, the hope is that he or she becomes STEM literate and pursue a career in a STEM field.

A closer look at the relevant literature revealed a lack of clarity in the focus of STEM Education. The acronym is defined in various ways and has several connotations contingent on the teacher, administrator, state department personnel or politician. Out of the many interpretations, ideas have emerged that stress the importance of K-12 discipline integration. Yet, depending on the grade band and school, the appearance of integration can look very different. In many schools, integration is in the form of the science classroom incorporating mathematics as a tool for statistics and to calculate measurement. There is a call to expand this perspective and provide a richer and more meaningful learning experience.

This literature review is divided into four parts. First, I will examine the development of STEM education historically to provide a context to why STEM Education is relevant and important. A review of science and mathematics instructional models will provide the platform on which STEM is constructed. Major national events that inspired government policy and change will be discussed. The discussion will lead to an examination of how the writing of national science and mathematics standards influenced the development of STEM.

Secondly, I will explore successful designs and implementation of integrative STEM in K-12 grades. The integrative STEM instructional model will be defined to provide a foundation for how the STEM disciplines are woven together. Strategies of implementation will be identified and discussed. Literature on the inclusion of the engineering design cycle will be reviewed. The role of engineering and technology will be examined in integrative STEM education. A discussion will examine how *Common Core Mathematics Standards* and *Next Generation Science Standards* both call for integration across disciplines and inclusion of the engineering design cycle into instruction.

Next, I will focus on instructional practices. This section will discuss the role of pedagogical practices such as problem-based, cased based and inquiry based learning in STEM. The use of robotics, 3-D design and printing will be considered. Finally, the last section will investigate methodological challenges and literature gaps. These challenges include an examination of how research is defined, how areas of inquiry are determined and how evidence is presented to achieve the goal of successful problem based integrative STEM education. With STEM being a relatively new area of inquiry, the gaps in the literature will be highlighted.

Development of STEM

The literature review on the development of STEM will focus on the need for STEM and provide a brief historical context.

The Need for STEM

US News (2014) reports that according to their recent rankings of the 100 best jobs in 2014, 10 out of the top 10 best jobs listed are careers rooted in science, technology, engineering and mathematics. For the first time in the history of their rankings, the number one career is in the technology field. Software Developer is at the top of the list with a forecast of nearly 140,000 brand new positions predicted before 2022. With over half of the top 100 careers belonging to a STEM field, the business and industry sector have pressured education leaders to prepare students to critically think, problem solve and be STEM proficient and literate. The appropriate time of instruction to address these concerns is important. Hossain and Robinson (2012) argue that researchers have determined that the skills and competencies needed for these careers are developed during the late elementary and middle school years. Hossain and Robinson (2012) claim that between the fourth grade and eighth grade developmental period is where students make choices to study STEM subjects. The literature reflects that an increase of STEM programming occurred in the upper elementary to middle grades. With students graduating without STEM competencies and skills, the demand is not being met. The looming prospects reported by the White House have determined that STEM education will be a focus of policy in efforts to address the needs.

Historical Context

Reform of education has been constant since the start of the 1900's. Ma (2013) credits the October 4, 1957 Russian launch of the first artificial satellite, Sputnik, as the launching point for the modern movement to examine science and mathematics education in the United States. The short flight of the satellite alarmed citizens. The launch was perceived as a threat to the general public of the United States. Wissehr et al. (2011) affirm that not only did concern grow that Russia was a major cold war threat of the time, but the United States was losing the technology race to them as well. The perception of Russia's military superiority was determined by Sputnik's launch. This motivated America to critically assess their ability to compete. One of the areas of response identified was to improve education.

The improvement of education called for reform of science and mathematics education. Science and mathematics educators were excited about the possibility of designing and implementing innovative rigorous curriculum. As Jolly (2009) maintains, Title III of NDEA (National Defense Education Act) provided states with matching funds to strengthen mathematics, science and foreign language instruction. The funding would include better equipment, resources, and professional development for teachers. Along with a focus on improving teachers, the NDEA also provided funding for programming to increase interest and participation for students going into science or mathematics research.

Dancy and Johnson (2010) assert that instructional practices in science and mathematics classes relied heavily on basic lecture and rote memorization at the turn of the century. These predominant methods of instruction prevailed instead of engaging and thought provoking teaching and learning experiences. Instruction of the science laboratories relied on step-by-step instructions with sterile predetermined results. National Science Board (2007) maintained that these instructional practices led to a STEM illiterate America. Students were graduating without critical thinking skills and a depth of content knowledge. Burke and McNeill (2011) affirm that new methods would have to be explored to address the substandard academic performance in schools.

Breiner et al. (2012) argue that at the beginning of the century, the letters of SMET were rearranged to form STEM. Vasquez (2014) further holds that former Director of NSF, Dr. Judith Ramley was the first to coin the term. Dr. Ramley believed that SMET sounded too close to smut and incidentally placed superiority on science and mathematics because of their order in the term. Breiner et al. (2012) state that Dr. Ramley wanted to emphasize the application of science and mathematics by placing them on the outside of technology and engineering.

With the separate letters in the acronym STEM being taught in their respective silos well into the turn of the new century, each acquired a particular definition. Dugger (2010) says that each of the letters in STEM were defined as such: science is concerned with what exists in the natural world, technology is the modification of the natural world, engineering is the profession where the knowledge of math and science are used to develop for the benefit of mankind, and mathematics is the science of patterns and relationships. Bybee (2010) argues that STEM will have to go beyond the acronym and determine its meaningful existence and determine what it means for educational policies, programs and practices. This initiative will provide a blueprint for consensus. Identified in the blueprint will be standard practices and strategies that will promote success in STEM teaching and learning.

Integration to Integrative STEM

Heil (2013) argues that after the coined conception, there was still considerable confusion on what STEM education was and how it looked. Definitions of this newly formed space varied from class to class, school to school, district to district and state to state. Stolhmann (2012) asserts that the idea of interdisciplinary education is beneficial and needed. The concept of interdisciplinary instruction was not new. But as claimed by Heil (2013), there was no consensus on a succinct definition of integrated STEM instruction or a description of the appearance of integration in the classroom.

Dugger (2010) maintains that there are a number of ways to teach STEM that utilizes several strategies of integration. One method of STEM instruction is by teaching each discipline separately without integration. Hernandez et al. (2014) hold that this manner of instruction neglects technology and engineering but focuses only on mathematics and science. This method continues the traditional manner of teaching these subjects independently from the other. Dugger (2010) claims another method of STEM instruction is where engineering is integrated into science, mathematics and technology. Becker (2014) affirms an example of how the implementation of an engineering design project focusing on water sources was used in an 8^{th} grade science class. The water sources and water cycle are the main concepts instructed and the engineering design cycle is used to facilitate the problem solving for the challenge. Another method claimed by Dugger (2010) is a comprehensive approach to integrating all of the disciplines. This method teaches the combination of all the disciplines into one integrated subject. Reeve (2015) characterizes this approach as a space where real world lessons are coupled with rigorous and relevant science, technology, engineering and mathematics concepts. The concepts are related and taught appropriately in the same lesson, same time and same classroom. The literature describes this space as the ideal level of integration. Dugger (2010) argues that the manner of instruction prevalent in schools today is where emphasis is placed on two of the four disciplines. The two disciplines most likely to be integrated are mathematics and science. As Hansen and Gonzalez (2014) state that integration focused on math and science is easily implemented. Robertson and Carrejo (2011) give an example of teachers using modeling as an approach to integrate mathematics and science concepts. Inquiry activities were discussed that use mathematical modeling to unify key physics concepts. The idea that is in agreement of all of the methods of integration except the first manner, as stated by Breiner et al. (2012), is that integration should be purposeful and deliberate.

Many States have utilized standards to motivate integration. Dobson et al. (2013) reveal that state and local education agencies are adopting their version of the *Common Core Mathematics Standards* and the *Next Generation Science Standards*. Capraro (2014) contends that *Common Core Mathematics Standards* challenge students to apply mathematical thinking to real world situations and engage in mathematical thinking and reasoning. Many of the activities that exercised mathematical thinking could be connected to other disciplines, such as science and art. The same movement could be seen in the science standards. Kracjik (2014) voices that there is a concurrent movement to integrate science concepts contextually with other disciplines. The movement allows for the integration of science, mathematics and engineering concepts. For example, the understanding of human locomotion can lead to the engineering of prosthetic limbs for injured soldiers returning from war. Capraro (2014) offers another example how the concepts of data analysis and science are integrated to provide opportunities for students to make data driven decisions using modeling. In this example, integration is motivated by the mathematical practices in the *Common Core* and the crosscutting concepts of the *Next Generation Science Standards.* Both practices focus on problem solving using models. Ardito (2014) supplies an example how robotic models were used in an authentic context to explore the concepts of force of motion and measurement.

Wang et al. (20011) argue that the movement was not only in mathematics and science standards, but was in the emergence of engineering and technology standards as well. In engineering standards, the focus of STEM education and integration should be on the application of mathematics, science and engineering design. Hernadez et al. (2014) maintain that the presence of engineering standards puts emphasis on process and design of solutions. With the focus of the universal systems model and the engineering design cycle in instruction, students are engaged in meaningful experiences in the application of science, mathematics and technology. The literature shows students participating as scientists and engineers conducting experiments, analyzing and interpreting data.

The presence of various strategies to integrate STEM disciplines shows an area of growth to develop a unified definition. Basham et al. (2010) argue a common theme echoed in the literature that integrating all disciplines across the curriculum is a main characteristic. Heil (2013) further describes the common theme of integration as spaces where students are challenged to problem solve and engage in inquiry. Science and mathematics content and processes are explicitly integrated with engineering and technology. But as Heil (2013) contends, integration is more than the merging of concepts. Kain (1993) argues that there are two purposes for integration: 1) to increase engagement and 2) to increase performance. Thus, the idea of integrative STEM is conceived. Wells (2013) defines integrative STEM as the application of technological/engineering design approach to teach mathematics and science concepts at the same time. Sanders (2009) deepens the definition by arguing that integrative STEM education includes research and design in efforts to solve a real world problem in an authentic context. Integrative STEM also is not exclusive from other disciplines, but is inclusive of concepts from language arts to social studies. Dugger (2010) argues that this is the most progressive view of STEM integration. Breiner et al. (2012) describe the integration as the instruction of one cohesive entity. This manner of integration is similar to how STEM professionals naturally work in this space without sectioning the individual STEM disciplines. Reeve (2015) claims that students engaging in integrative STEM perform the same practices as engineers applying principles from mathematics and science.

Instructional Practices

Pedagogical Approach

Huber (2002) argues that pedagogy refers to the method and practice of teaching. Glasgow (1997) contends that the student-centered model assigns the role of guide and facilitator to the teacher. The teacher-centered model views the teacher as the expert and deliverer of knowledge. Heil (2013) declares that many student-centered models are being used in integrative STEM. The models include, but are not limited to, case-based, guided inquiry and project/problem based learning. Holstein (2013) shows teachers using guided inquiry to implement mathematical decision-making curriculum. The emphasis of the curriculum is using mathematical models based on technology and engineering concepts to solve real world problems. Gehlhar and Duffield (2015) explain how teachers use case-based techniques to promote students to become global thinkers while building awareness of STEM related fields.

Smith et al. (2009) argue that project/problem based learning strategies work well with integrative STEM teaching and learning. Project/problem based learning involves the process of working toward a solution or a challenge. Savery (2015) claims that project/problem based learning is a student centered approach where the learner integrates theory and practice to develop solutions to problems or challenges. A critical component to the approach is the selection of a real world, ill structured problem. The problem represents an authentic context for the application of the concepts and skills acquired. The teacher becomes a guide and facilitator in the learning process. Capraro (2014) states that problem/project based learning affords the students the ability to collaboratively engage with other students in the problem solving process while receiving guidance from their teacher. Savery (2015) outlines characteristics of project/problem based learning which include: 1) students take control of their own learning, 2) ill structure design of the problem, 3) the integration of many disciplines, 4) essential collaboration, 5) communication of concepts learned, 6) self and peer assessment and 7) project/problem based learning must be the pedagogical base of the curriculum.

Estes, Liu, Zha and Reedy (2014) claim that the belief of how learning is done and meaning is acquired should be reflected in the design of the learning space. For collaboration to be effective in project based learning, the classroom has to afford them the opportunity to discuss, perform research and test ideas and claims. The learning space has large round tables especially designed for collaboration around computer workstations where work can be viewed equally from different positions. Students are encouraged to work together as they research, plan, design, test and iterate the solution to the challenges. These characteristics are found in the literature to be successful aspects of integrative STEM instructional models.

Project-based learning mainly involves areas of constructivism and situated learning theories. Blumenfeld (1991) argues that students join together and cooperate to solve an authentic problem. Based on prior knowledge, students collectively construct new knowledge. Marra (2014) argues that when engaged in this approach, students are given the opportunity to construct knowledge as a member of a community of learners that participate in teamwork and problem solving using various but shared methods. Project-based learning has shown in many studies that learners are benefited by group problem solving experiences and gain knowledge where there is an opportunity for various outcomes and solutions. Strobel and van Barneveld (2009) concluded through a qualitative synthesis of a meta analyses of problem based learning that the effectiveness of teaching is enhanced using this method. Tseng, Chang, Lou and Chen (2011) assert that using problem based learning enhances the student engagement and interest in STEM concepts. Their study's purpose was to understand student motivation and attitudes while engaging in an electric vehicle challenge.

Tamim (2013) claims that teachers use project/problem based learning as a way to initiate, navigate, reinforce or extend content. Concepts can be introduced with a problem or a challenge to create student interest. When used as a lesson starter, student inquiry can generate motivation to research the concepts taught. Using the project/problem based learning experience to navigate content gives the teacher opportunity to teach the concept where it naturally occurs. The answer to the student's question, "when will I ever use this", is answered. Using project/problem based learning techniques to reinforce or extend concepts presents opportunities for the teacher to use an alternative assessment to written tests. Jones et al. (2014) explain that collaborative project-based learning experiences can also be used as a capstone project to assess learning at the end of a course.

Estes et al. (2014) argue that the problem based learning environment is active and promotes engagement and collaboration. The literature agrees with this statement. Kolodner, Camp, Crismon, Fasse, Gray, Holbrook and Ryan (2003) affirm the use of challenge activities, such as balloon powered vehicles to motivate collaboration between students. The study contends that situating the students as practitioners in a context that represents a real world problem engages and interests the learners. The STEM learning environment must be designed for active, student-centered, project based learning experiences. The environment must allow for authentic activities designed to show STEM relevancy and connections to STEM careers. The learning environment must also relate to students' interests and develop skills that will aid the students in their field of interest. Tamin (2013) argues that the design of the space permits students to engage in the iterative process of research, design, solve, test, and redesign. The collaboration of students will promote the development of critical thinking skills needed to become successful in STEM concepts.

Innovative Instructional Technology

Grubbs (2014) argues that technology influenced education with the America's participation in the Space Race and was motivated by the technology rich event of placing men on the moon. Technology motivated education reform but was absent in the use of daily classroom instruction. The literature discusses the current instructional technology that increases the quality of current integrative STEM education.

Catlin (2012) explains that educational robotics engage students in learning activities mediated by technology requiring solutions to problems using engineering. Alemdar and Rosen (2011) affirm that robotics is an effective tool that is used in the integrative STEM classroom. Casteldine (2011) contends that using robotics in an instructional setting has the ability to motivate problem solving and encourage innovation. In the effort to develop these skills, the literature points to the use of the robotics platform to motivate student inquiry and sharpen investigation and experimentation skills. As the use of the robotics platform grows, the need to expand their use into the engineering discipline becomes increasingly apparent (Casteldine, 2011).

By the same token, Ardito et al. (2014) describe the use of the robotics in a sixth grade classroom. The goal of the instruction was to introduce the robots in a manner that explores the relationship between the learned concepts in mathematics and robots. This was done in a manner where the students intuitively connected the skills. Problem solving skills were nurtured and inquiry was encouraged. Benitti (2012) argues that robotics has been used to support other disciplines, but there is a shift in the role robotics will play in the future of integrative STEM.

Furthermore, Schelly et al. (2015) explain that robotics competitions and races began to give way to innovation and creation with the emergence of 3-D printing. Eisenberg (2013) reports that with manufacturing and innovation being seen as a place of weakness for U.S. students, 3-D design and printing provides opportunities for students to gain these competencies. Also, using prototyping activities offers exposure and experience that is very close to real world application. With the emergence of real time technology, the organization of the school environment and instructional design are constantly changing in the literature. Lipson (2007) argues that 3-D printing and prototyping engages the students in active learning. Students are able to feel and touch the prototype model and have discussions about their design. Also, Schelly et al. (2015) explain that 3-D prototyping leads to students becoming proficient in data driven decision making and being contributors as well as consumers of content and knowledge.

The literature informs that these developments in the use of robot technology lead to unique integrative STEM experiences. Brown (2012) discusses how the development of technology has created ways to integrate science and technology in a manner where true collaboration between the disciplines can occur. He discusses how technology is the discipline that can inspire, ease and motivate the integration with the other disciplines. Wells (2013) reports that the underpinning of technology leads to the definition of the concept of integrative STEM. Wells (2013) calls this manner of integration a new paradigm where technology/engineering, design based activities are used to intentionally teach core discipline concepts.

Related Studies

An examination of the literature shows a wide range of studies with varied purposes. For example, some studies were conducted at all grade bands from elementary schools to undergraduate levels, while others focused on instruction outside of the normal school day. However, these studies had little focus on STEM student performance and engagement (Brown, 2012). PCAST (2010) highlights the fact that upper elementary to middle school are periods of interest to study. Nevertheless, very few studies have been conducted to show STEM student performance and engagement during regular instruction at the middle school level.

Inspecting the literature, it is clear that there is emphasis on two major areas: 1) student engagement in STEM as extracurricular activities and 2) student self-efficacy after participating in a STEM activity.

For example, Yuen, Boecking, Tiger, Gomez, Guillen, Arreguin and Stone (2014) conducted a study examining the nature of community and collaboration and how it developed during elementary and middle school students' engagement in a summer robotics camp. The researchers investigated the type of group tasks, activities, dynamics and interactions that occurred during collaborative projects and predicted on-task behavior. The participants for the study were 3rd to 8th grade camp attendees assigned by the researchers. The quantitative study was conducted using group observational forms and behaviors were recorded using momentary time sampling by determining the percentage of occurrences in a ten-minute observational period. A stepwise multiple regression was used to find predictors for on-task behavior. The study found that children were mostly on-task during the collaborative robotics projects. Students were close in proximity with their group and did not exclude others from working with the group. Discussion plays a large part of the collaborative process. Students were engaged in discussion during problem solving as well as conversations that addressed the team's work on the solution for the challenge. The study showed that the collaboration observed justified the use of group projects using robotics in a problem based learning environment. During the study, there was an unscheduled regrouping of the students. The researchers did not anticipate movement between the groups. Therefore, the researchers could not track the students as they moved from one group to another. Furthermore, the camp was independent from the researchers thus the researchers did not have any input in the structure of the camp.

In a similar manner, Barrett, Moran and Woods (2014) developed a study that measures the changes in students' knowledge and understanding after engaging in a STEM unit during a summer camp. The study investigated how the integration of meteorology and engineering changed student engagement and performance. The Naval Academy Department of Oceanography and Mechanical Engineering developed an interdisciplinary unit for their summer STEM camp. The module was intended to present basic concepts in meteorology and engineering. The result was the design of a prototype that was be tested in a wind tunnel. The goal of the unit was to improve awareness of severe weather hazards. The module's objectives were to increase student knowledge about meteorological factors associated with tornadoes and increase their understanding of structures in high wind environments. The quantitative study included approximately 160 participants ranging in age from 12 to 16. The study employed a pre/post test design with classroom observations. The outcomes indicated that the students learned content in both meteorology and engineering. The study documented content learning as a major finding due to the fact that most studies do not report this occurrence. The researcher mentioned a number of limitations including the small number of items on the pre/post test, the pre/post test only attended to short term learning, and the project occurred outside of the school day.

For an example involving robotics competition, ChanJin, Cartwright and Cole (2014) evaluated the impact of participating in a robotics competition in upper elementary to middle schools across several states. The competition lasted 3 to 4 months with students engaged in afterschool experiences. The study was based on beliefs that using a robotics based pedagogy offered opportunities for multidisciplinary integration, transference of abstract concepts into real world applications and engaged students in meaningful hands on learning opportunities. The goals of the study were to attract students to STEM subjects and careers and increase preparedness for college by increasing proficiency in STEM disciplines. The study used robotics competitions to teach mathematics and science concepts including but not limited to, numbers and operations, algebra and force of motion. Students in the control group were from the southeastern portion of a particular state. The students that formed the experimental group were randomly chosen from different states. Instruments used were pre/post assessments aligned to 5^{th} through 8^{th} grade mathematics concepts. The findings reported improved mathematics scores as students participated in the robotics competition. Several limitations were identified by the researchers. The control group represented the general US population. However, in regards to gender, the experimental group displayed an unbalanced gender representation in favor of males. Moreover, the experimental group had prerequisite knowledge of STEM and had a high interest. There was no concrete incentive for the students to do well on the assessment which may have influenced assessment scores.

On the other hand, in the area of gaming, Alfieri, Shoop, and Schunn’s (2015) study examined the use of a computer based 3D robot game to teach engineering design and proportional reasoning skills with a focus of reinforcing mathematics understanding. The case study was designed to investigate effects within three diverse sites. Approximately 120 students participated from grades 6 to 8. The study employed pre/post tests, prior experience and motivation surveys. The pre/post tests were analyzed first using ANCOVA and then by paired sample *t*-tests. Overall, the researcher's intervention improved scores on proportional reasoning. There was also an increase noted in student interest of mathematics using robotics. The improved outcomes were attributed to the instruction of a specific mathematics topic, simplicity of robot programming, the reduced need for guess and check and the presence of specific world problems associated with the general application of the intervention. The study was limited by the short duration, week long intervention time. The need for a longer study would address this issue. Also, the study's lack of a control group to give comparison brings forth another limitation.

In the area of self-efficacy and attitudes, Star, Chen, Taylor, Durkin, Dede and Chao (2014) evaluated the impact of technology based activities on the students' short term motivation for learning mathematics. The purpose of the study was to explore the impact of the four-day intervention on student's motivation in mathematics and the extent of the impact influenced by the type and nature of the technology used. The three different technology environments included virtual environment, web based pre-packaged curricular activity and video. The researchers hypothesized that the virtual environment and the web based activity would have the strongest impact. The quantitative study was conducted with 350 teachers and 19,000 students from 38 elementary and 12 middle schools. For the research, a pre/post test experimental design was used. After the pretest administration, teachers were randomly assigned to one of the three technology interventions. Data was collected to provide a description on the quality of implementation in regards to professional development and math lesson implementation. Analysis of the data revealed no significant gains found in the students' self-efficacy. With respect to the students' view on math learning, all three technology interventions had modest improvements. The impact of the technology and student level factors had moderate influence on the motivational impact of the technology intervention. Data showed that the second technology intervention was more successful over the other two. The researchers reported several limitations including the large amount of missing data, short duration of the study and absence of the posttest at the end of the intervention.

Another international study examining student attitudes was conducted by Cuperman (2013) in Israel, which highlighted the relationship between engineering and science. In this examination, the students were immersed in the process of learning by doing while at the same time investigating and exploring science concepts. The learning by doing included hands on activities that related to the concepts instructed. The investigation reviews the specific features of learning presented during this approach and the students' attitudes towards this learning practice. The study used a multi-case framework based on grounded theory methodology. Constant comparison procedures of data collection and refinement were focused on robot design, redesign, learning activities, prototypes and perception of learning with models. The researchers found that students were highly engaged and motivated to learn scientific and technological concepts using models that facilitated the learning and understanding of biological and engineering concepts. A major limitation was reported, namely the lack of triangulation between student questionnaires and interviews was not addressed in the study.

The studies reviewed present findings that did not address STEM discipline integration and its impact on learning in the mathematics classroom. Also missing from the literature are the potential factors that influence student engagement and performance when students are engaged in STEM instruction during the school day. Brown (2012) and others claim that there is a need for rigorous mixed methods research that examine the impact of integrative STEM on student performance, proficiency and engagement.

Literature Gaps

The review of the literature presents four gaps where two methodological challenges emerge. The first methodological challenge that unfolds in the literature reflects the lack of longitudinal studies that investigate the impact of integrative STEM over an extended time. The inspection of the literature does not provide longitudinal studies showing a correlation between integrative STEM instruction dosage to engagement and proficiency in STEM disciplines for secondary and post-secondary grade levels. Secondly, Brown (2012) argues that with the newness of integrative STEM teaching and learning, there is a challenge to show a causal relationship between integrative STEM teaching and student performance. Empirical research is lacking that reports the explicit investigation of how STEM experiences lead to hypothesized outcomes.

With regards to the gaps, the literature calls for a narrower focus and strategic definition of research in the field of STEM education. Brown (2012) states that the literature shows varied instruction of STEM integrated concepts and there are inconsistencies on how to effectively design and implement an integrative STEM learning environment. The literature reveals a need for research committed to defining STEM integration and providing evidence of successful strategies.

Thirdly, with the lack of STEM integration focus in the literature, there are many ways to show and provide evidence of the outcomes. The literature does not show evidence presented that can lead to reform of instructional practices. Smargorinsky (1995) insists that it can be problematic if the data collected does not lead to analysis that produces evidence that demonstrates development and advancement. Often evidence may address the individual disciplines in STEM and not the integration of STEM. Evidence from the analysis should focus on the integrative nature of STEM and how it is instructed. Brown (2012) contends that the analysis should be focused on the outcomes that inform strategies of implementation of integrative STEM curriculum. Several models of implementation could include the instruction of the curriculum in an elective or connections strand or the instruction of the curriculum in a single discipline class that integrates the other disciplines in the same learning experience.

Lastly, the literature is lacking a detailed description of implemented integrative STEM curriculum. Specifically missing is the research showing how integrative STEM curriculum reaches high level mathematics skills and goes beyond concepts of statistics and measurement. The literature does not address how the curriculum supports the integrative STEM teaching and learning environment. The effectiveness of the curriculum has not been reported and is widely missing in the literature. Brown et al. (2011) state that there is an area available to explore the curriculum's effectiveness and how it supports the ideology of integrative STEM.

Generally, STEM education research has been done with a solid base of a wide range of methods and analysis, but suggests that the area of research regarding description be explored in detail and depth (Brown, 2012). The literature begins the exploration of some strategies used in instruction and their effect on student engagement. Problem–based learning is highlighted as a major instructional strategy that is widely used. The need to develop critical thinkers and problem solvers is evident across the literature. The gaps show there is a need to do research that unveil characteristics of effective integrative STEM curriculum and teaching during normal school hours. The research should provide an understanding and description of the learning environment to inform instructional design and influence student performance and engagement.

CHAPTER 3

Methodology

The purpose of this study was to investigate and describe the effects of using project-based integrative STEM modules on eighth grade students' performance and engagement in a unit on functions in Algebra. The study was guided by the following research questions:

1. What is the effect of using project-based, integrative STEM modules on 8^{th} grade student performance and engagement in learning a unit on linear functions? More specifically, to what extent are grade 8 students able to make connections between linear functions and its applications?
2. What STEM-related situational factors contribute to 8th grade students' success in learning using project based, integrative STEM modules?

Research Design

This study employed an exploratory single case study approach. Yin (2014) states that the motivation for doing case study research lies in the interest to understand a real world case. By developing understanding for this real world case, reasons and conditions that are related to the case will become apparent. Yin (2014) further declares that there are three conditions that could determine the use of case study: 1) the manner of research question, 2) the degree of researcher control and 3) the degree of focus on contemporary events desired. The first condition will be discussed later in the research design. Yin (2014) reasons, according to the second condition, that case study is preferred when the examination of the event is done in real time, but relevant behaviors cannot be managed. Direct observation of the integrative STEM instruction enabled exploration of the factors that influence student performance and engagement. The second condition was also addressed by the acknowledgement that the motivation to examine the intervention, the instruction of integrative STEM module, provided opportunity to collect data from many different sources. As Yin (2014) holds, the presence of many different sources does not require control of the researcher.

The case study can be classified as exploratory due to the nature of the questions as required by the first condition mentioned earlier. Yin (2014) argues that “what” questions are exploratory due to the ability to develop hypotheses and propositions that can be further studied. Gomez (2013) expresses that the integrative STEM education model is a fairly new area of research and in search of a systematic approach to meet the demands currently placed on schools. Acknowledging the relatively newness of integrative STEM teaching and learning justifies the use and rationale to conduct an exploratory case study (Yin, 2014). The interest, as Thomas (2014) asserts, lies in exploring a phenomena or events that warrant an investigation into areas that lead to further discoveries.

This case study is bounded by the project based learning instruction, the integrative STEM curriculum and the use of instructional technology (robotics kits, 3-D design and printing) in two 8^{th} grade mathematics classes. The case is further bounded by the 8^{th} grade pacing guide for the curriculum. The integrative STEM unit covers concepts and standards addressed in the school’s second quarter of the first semester pacing guide. The mathematics concepts included single variable equations and linear functions and the science concepts included force of motion and the practice of data visualization.

Yin (2014) argues that to explore a case that is unusual and deviates from everyday practice, a single case design should be employed. Pinnell et al. (2013) maintain that the integrative STEM model is relatively new and differs in the instructional practices currently used in the classroom. Bybee (2010) argues that one of the most significant challenges in STEM instruction is introducing real world context into instruction. The hurdle calls for an approach to instruction that emphasizes addressing the real life problem and situation in the development of concepts and practices. Clearing this hurdle calls for a change from the lecture of abstract concepts to the application of context based instruction. Resta, Christal, Ferneding and Puthoff (1999) claim that the use of technology as a tool to change teacher practice presents a significant challenge. Roles of the teacher and the student are changed as a new manner of instruction is implemented. The learning environment is new and contrasts what is done in traditional schooling. As Yin (2014) states, an extreme or unique case is a rationale for single case design. The manner of student engagement and participation in this unique STEM teaching and learning model used in this study explored and identified effective strategies using real world contexts and real time instructional technology (i.e. 3-D prototyping).

The single exploratory case study was employed at one purposefully selected school. The school was purposefully selected due to the availability of resources needed for the instruction of the curriculum. The study investigated the experience of students designing and testing 3-D printed prototypes in response to an engineering design challenge. During the study, students collaborated in groups to design and create a foot like device for a robot model of an insect. The major goal for the students was to better the performance and efficiency of the robotic insect's movement. The uniqueness of the activity begins with students approaching the challenge using the engineering design cycle developed by Hynes et al. (2011). Students conducted the same practices and used the same tools that engineers currently use to respond to the design challenge. Through testing and data collection, students used data to drive decisions to facilitate and aid the problem solving process. For example, students used graphs and calculations to determine the evidence of slippage in the robot's movement. The gathering of data helped the students make decisions for the design of the foot like device. Bybee (2010) argues that the manner of data driven instruction is uncommon in classrooms. Also, the instruction occurred in a school in a high needs district. The school lacks access to tools and resources currently used in industry, much less average classrooms in the district. Providing the school with these tools and resources allowed for the investigation of the influence these items had on students who usually would not have access to these resources. Yin (2014) states that testing the benefits of a unique event can be investigated using an exploratory case study. For the reasons stated earlier, the use of single exploratory case design was warranted.

Research Setting

The study was conducted in an urban middle school located in a major southeastern city of the United States. The school neighborhood recently transformed from a low-income area to one of the fastest gentrified communities in the United States. The school serves a high poverty community with nearly all of the students participating in the free or reduced lunch program. During the time of the study, the percentage of students participating in the free or reduced lunch program was more than the 60% of students state-wide.

The school is characterized by having a high minority population enrolled with mostly Black female students in the eighth grade. Close to a third of the 8th grade students failed the district mathematics standardized test, compared to the district average of approximately 25%. For the district science standardized test, a third of 8th grade students have failed the test compared to 30% of district middle school students during the period of the study. The school divides students into two instructional teams per grade level. Each instructional team includes a social studies, English/language arts, science and mathematics teacher. Students are pulled from the teams based on gifted or special needs instruction per individual education plans. The school also allows for inclusion of certain special needs students. The school participates in an afterschool robotics competition.

Sampling Techniques and Participation

Selection of the curricular participants began with the solicitation of schools giving them the opportunity to participate in professional development for teachers from various disciplines. The training was part of a federally funded project to improve teacher quality in high need districts as per the free/reduced lunch criteria. Teachers were assigned by school administration to participate in a robotics and engineering design professional development workshop. The 24-hr workshop trained the teachers on the implementation of an integrative STEM curriculum where a project-based design challenge is solved using the engineering design cycle. Using purposive sampling, two teachers were chosen based on their willingness to implement the curriculum in their mathematics and science classrooms. During the professional development training, two teachers demonstrated understanding of the curriculum goals and expressed interest in implementing the modules. Subsequently they were asked to participate in the study. Students were selected from two randomly chosen classes to comprise the sample of the study.

The sample included 54 eighth grade students from the two mathematics classes selected randomly from a pool of four classes. Students were administered pre/post test and an engagement survey. The pretest was administered one week before the intervention and the post test was administered one week after the intervention.

For qualitative analysis, a subsample of seven students was collected, three from one mathematics class and four from the other mathematics class. These students were selected randomly to participate in interviews using a random number generator. The last four digits of their student number were entered into the random number generator and selected. Observations of class behaviors and related items were made from the qualitative sample. Students were interviewed to discuss areas of interest, engagement, nature of the learning environment and performance. Interviews included discussions with the students on their ability to make connections across the STEM disciplines.

Integrative STEM Curriculum

The instruction of the integrative STEM modules took place over five weeks. The module's focused on the construction and application of knowledge and skills guided by the engineering design process. At the heart of the investigation was the relationship between project-based instruction, STEM content integration and technology inclusion to achieve learning gains in STEM disciplines (Hansen, 2014). The curriculum used was the Robotics and Engineering Design Curriculum (REDC), an intervention developed by Georgia Tech's Center for Education Integrating Science, Mathematics, and Computing (CEISMC) and funded by Race to the Top (RT3) and the Georgia Department of Education. I served as the Project Director and Team Lead for the development of the curriculum.

The REDC presents an alternative instructional philosophy that changes the traditional instructional environment used in classes to a project-based, integrative STEM environment. Wells (2013) describes the term integrative as an ongoing, dynamic, student-centered process of teaching and learning emphasized in this instructional design. The REDC is aligned to the Georgia Performance Standards 8th grade physical science, 8th grade mathematics Georgia Standards of Excellence, and 8th grade Technology Systems Career Tech and Agricultural Education (CTAE) course. Through project work, students formulated questions, conducted research, collected data, and engineered and designed solutions. The REDC utilizes engineering design, robotics, and 3-D prototyping and manufacturing to teach four standalone units integrated with algebra and geometry; 1) biomechanics, 2) electromagnetic radiation and waves, 3) energy and 4) analog to digital electric circuits. The purpose and content of the teacher training aligned with the activities in the biomechanics unit. Thus, the biomechanics unit was used for this study.

The curriculum is designed on the platform of the universal systems model and the engineering design cycle. The foundation of the curriculum assumes that learning and instruction occurs across various instructional strategies and includes the belief that students actively engage in their learning process and the development of content. Students were given the opportunity to reflect and assess their knowledge and develop new tools and resources based on prior knowledge. The development and use of these tools during the socialization of the classroom is imperative to the learning environment (Hernandez, 2014). These beliefs undergird the use of the engineering design process. Through the process, students designed their own experiments to address the project-based learning experience and engaged in collaborative learning. The engineering design cycle places priority on process and solution design and not solely on the solution itself.

The study utilized the biomechanics unit. The unit provided 45 to 50 minutes of instruction for several days each week during the five weeks. The unit is sectioned into seven investigations. Investigation 1 is the launcher of the unit and introduces the students to the engineering design cycle and the Request for Proposal

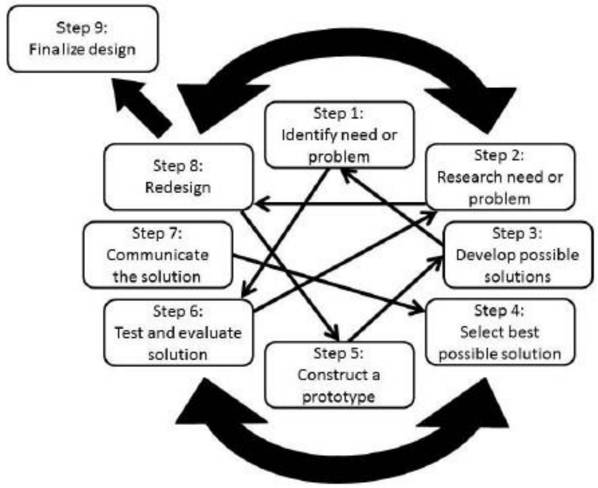


Figure 3. The Engineering Design Model. Adapted from "Infusing engineering design into high school STEM courses," by M. Hynes, M. Portsmore, E. Dare, C. Rogers and D. Hammer, 2011, National Center for Engineering and Technology Education website, p. 3. Copyright 2011 by the National Center for Engineering Technology.

The REDC biomechanics unit used the model from Hynes et al. (2011) of engineering design that correlates to the model shown above in Figure 3. The model shows a series of steps used to solve problems. The process is cyclical and iterative. The iterations made to the proposed solutions are prompted by data collection and analysis. Students are able to shift back and forth through components to derive the desired solution. The Request for Proposal (RFP) is a solicitation by an agency or company looking for goods and/or services from other companies using a bidding process. The use of the RFP in the curriculum situated the students in the context of a design or engineering firm. In this context, students performed activities that were common to entities involved in this process. The investigation has activities that provided an overview of the process used for the remainder of the unit. Students took part in activities which included an introduction to the week's challenge, explanation of the RFP, discussion of criteria and constraints, brainstorming, creating, testing, improvement on design and presentation. Activities correlated to the steps of the engineering design cycle.

The study utilized portions of the described curriculum above and was taught in a science and mathematics class simultaneously. The science class presented the challenge listed in the RFP. Table 1 below lists the investigations and activities conducted in this study as well as the duration for these activities. The launcher investigation 1is a preview investigation and is used as a launcher for the curriculum. Due to instructional time constraints, Investigation1 was not used.

Investigation 1 is a common launcher activity that introduces students to the universal systems model. Students are introduced to how engineering firms respond to a request for proposal (RFP) and the process used to respond to the request. The investigation is the same for all four units and addresses student inquiry standards and skills.

Investigation 2 introduced the unit’s challenge. Students were asked to design a foot like device to increase the performance and effectiveness of a robotic insect’s motion. The robot was a predesigned model that replicated a six-legged bug. The class was situated in the context of assuming the role of an engineering design company. Instructional objectives included understanding locomotion, calculating velocity, and understanding gait.

Investigation 3 continued the student’s journey to designing a foot like device. The groups were still in step 2 of the engineering design cycle researching the problem and understanding the robotic system. In this investigation, students explored the concept of force and motion. Students were expected to make connections between solving velocity equations and the presence friction. The instructional objectives of this investigation were to describe how friction affects movement and velocity, identify the forces acting on the foot during locomotion and draw concept force diagrams of the movement.

Investigation 4 focused on using data to drive design thinking. Students performed experiments with the robot to determine how the robot moved over different surfaces. The data was recorded and analyzed in effort to influence the design of the robot's foot. Instructional objectives for investigation 4 included analyzing graphs to determine slope, use slope to describe motion, calculate slope to determine velocity and interpret data to make decisions on foot designs.

Investigation 5 began the stage of developing possible solutions. Students drafted different designs based on the data collected in the previous investigation. After the drafts were made, students used 3-D design software to design several possible solutions. Instructional objectives of this investigation were for students to use mathematical concepts of measurement and scale while utilizing a 3-D design software package for the drafting of their solutions.

Investigation 6 had the students print prototypes of their solutions from their drafted designs made with the 3-D design software. The prototypes were printed using a 3-D printer. The prototypes were tested to collect data. The data collected motivated iterations to the design. The students were in the redesign portion of the engineering design cycle. In this part of the cycle students moved to any step of the process necessary to redesign and draft iterations of the solution. The instructional objectives of this investigation were to modify, print and test designed iterations of the prototype.

Investigation 7 had the students compile their data, draft and design notes, as well as printed prototypes into a presentation. The presentation focused on why their design should be the one chosen to represent the engineering design company (class). Each group made a presentation explaining why their design was the best. Based on the presentations, the company (class) selected the winning prototype design.

Table 1

Instructional time of activities per Investigation

Investigation	Activities	Time Duration
Investigation 2	• Introduce RFP • Explore locomotion with robotic models • Graph the motion of the robots and calculate velocity	First week: 3 days
Investigation 3	• Explore locomotion with robotic models over 3 different surfaces • Graph the motion of the robots and calculate velocity and draw force diagrams	Second week: 3 days
Investigation 4 Investigation 5	• Use the data logging function to collect robot motion over smooth lined track • Analyze the graph. Determine slope and velocity from the graph. • Create designs for foot like device	Third Week: 3-4 days
Investigation 6	• Print, test and iterate designs of foot like device	Fourth Week: 3 days
Investigation 7	• Final presentation	Fifth Week: 1-2 days

Note. Investigations are taken from the Biomechanics Standards and Activity Matrix, see Appendix A.

Ashgar et al. (2012) state that the role of the teacher in a problem-based learning environment is that of a guide and facilitator. The teacher provided content in the manner prescribed by the curriculum. Most concepts were explored by developing new knowledge built upon the foundation of existing knowledge. Concepts of linearity and slope build upon the students' knowledge of equations, ratios and proportions. The Students gained real time training on the use of instructional technology such as robotics and 3-D printing. The programming and building of robotics was not a learning objective of the curriculum. The insect-robot model was pre-made by the teacher. The curriculum developers provided the robot programs. The students gained challenge specific training and knowledge in regards to the operation of the robot. Students acquired the skills of powering the robot, initiating the pre made program and operating the insect robot on different surfaces and conditions.

The curriculum design answers the call from PCAST to produce STEM proficient students who successfully perform the activities that are being performed by mathematicians and scientists in their respective professional careers (PCAST, 2010). The curriculum also focuses on the manufacturing and innovation aspect of engineering that has been highlighted as being a special need for American students. The overarching theme of manufacturing throughout the curriculum filled the need of developing student creativity and innovation while they were equipped with skills needed to use the tools found in the manufacturing sector.

The curriculum is designed with the intended purpose to use innovative tools, such as real time industry relevant robotics and 3-D printing, to provide context and relevance. The curriculum assumes that when the students are engaged in experimentation and data collection, similar to scientists and mathematicians in practice, the context will shape their identity and disengage the dominant narrative of “I cannot do this” and “Why are we learning this?”. The design, development and manufacturing of solution prototypes provide a unique look at how problem solving occurs. From the prototypes, students are able to perform experiments and collect data to inform the decisions made toward answering the challenge of the RFP.

Data Collection

Following Yin’s (2014) four principles of data collection: 1) using multiple sources of data, 2) creating a data management plan, 3) maintaining a chain of evidence, 4) securing the safety of the data, data was triangulated using multiple sources: tests, surveys, interviews, observations and collection of artifacts. These sources of evidence are all included in the six primary resources suggested by Yin (2014). The other principles of data collection, as stated by Yin (2014), creating and managing a database, insuring the safety and security of the evidence collected, and maintaining a chain of evidence will be discussed later in the paper.

Three qualitative and two quantitative data collection methods were used. Leech (2007) argues that collecting qualitative data allows for the exploration and understanding of factors of interest to the study. The factors of interest included the situational components that influence student performance during the learning of an integrative STEM unit on linear functions. The qualitative data collection techniques that allowed for the exploration of the complex integrative STEM model included: semi-structured interviews, observations and collection of artifacts. Quantitative data collection techniques included: pre/post tests and surveys to measure student performance and engagement during the instruction of an integrative STEM module.

Semi-structured interviews were conducted to understand the nature of the impact of the integrative STEM curriculum on student performance and engagement. Thomas (2011) defines semi-structured interviews as a guided conversation structured by an interview schedule with a list of issues or points to discuss. The interviews asked approximately 15 questions with some followed by further probing questions. Students reflected on the instructional practices and curriculum and described how their participation in this learning model helped form critical thinking and problem solving skills. As Thomas (2011) states, the conversation is not bound by sequential questioning but facilitated by the issues of discussion. Questions for the interview focused on prior knowledge of skills in the activity, specific concepts learned during the activity, ideas of the learning environment and what they thought of the experience as a whole. Interviews for each student were conducted once during the last week of the study. Each interview lasted between 45 - 60 minutes and was conducted in the media center. The sample protocol for the investigation can be found in Appendix B.

Observations were employed to observe the students as they interacted with each other in the integrative STEM environment. Yin (2014) argues that observational data is useful in obtaining information of a new technology or curriculum at work. The observations were used as a guide to explore how the curriculum tools, resources and environmental factors were related to the student's performance and engagement. The observation protocol developed by the University of North Carolina at Greensboro and supported by National Science Foundation and Race to The Top funding was used (Arshavsky, Edmunds, Charles, Rice, Argueta, Faber & Parker, 2012). The goal of the observation protocol was to describe the implemented curriculum as close as possible to the manner it was experienced by the students. Six questions guided the observation in telling the nature of the lesson. The observation looked for evidence in the following five areas: (1) student cognitive engagement in meaningful instruction, (2) student activities during project-based learning, (3) student engagement, (4) teacher instruction, and (5) classroom culture. The observations focused on student engagement in class activities, their interaction with the material, their construction of the solution prototype, the lesson topic and goals, and gave an account on curriculum materials used (See Appendix C). Two to three 55-minute observations were conducted in both classes each week for the duration of the study.

Artifacts including student notes contained in their engineering notebook and 3-D printed foot like device prototypes were collected during the study. Student notes included design drafts, data recordings from various experiments and student observations from testing. Artifacts provided an inspection into the engagement and performance of the students. The relationship of the draft to the actual product made showed how the student was able to focus and replicate a two dimensional object from a three dimensional perspective. Yin (2014) maintains that artifacts can be insightful into the use of technology and its impact on the case. The students' use of robotics and 3-D printing in this case provides a broader perspective into the students' thinking process individually and as a group. The notebooks will give a "real-time" view into the cognitive process used in the development of the skills and knowledge needed to produce the prototype for the project challenge. An engineering notebook was collected from each student at the end of the five weeks. The foot like device prototype showed the understanding of the concepts of force, motion and velocity. The understanding is demonstrated by the foot design that promotes the required amount of grip and reduces slippage. The prototype(s) were collected from each student group at the end of the five weeks. Photographs and videos were taken to observe the instruction of the integrative STEM activities and student engagement. Photographs of the design, printing and testing of the foot like device prototype and project-based instruction were taken during classroom observations. Photographs focused on students actively solving the project-based activity challenge.

Pre/post tests were administered to measure the effect of the integrative STEM instruction on student performance and engagement. The same test was administered at the beginning (pretest) and end of the instruction of the unit (posttest). The pre/post test measured any changes in student performance in mathematics, science and engineering integrated concepts covered in the curriculum. There were a total of 25 multiple-choice items for the Biomechanics pre/post test (Table 2), Due to research question number 1 being concerned with the effects the curriculum has on students' performance on linear equations and their application, only the mathematics questions results will be considered for the study. The duration of the pre/posttest was thirty minutes. The tests were administered in one class period. Students who were not present were tested on their first day back from their absence.

Table 2

Pre/Post Test Concepts and Number of Items Per Concept

Concept	Number of Items
1. Relationship between force, mass, and motion of objects.	
Calculate Velocity.	5
Determine the effect of unbalanced and balanced forces.	5
2. Expressions and Equations	
Calculate measurements in the metric system. Scaling from very small quantities to larger quantities. Determine appropriate units of measurement.	2
Graph proportional relationship; determine the rate of change for the relationship. Determine if the relationship is linear.	3
Determine if a relationship is a function. If the relationship is a function, determine if the function is increasing or decreasing.	3
Use a linear model to make data driven decisions.	2
3. Engineering Standards	
Identify the step of the engineering design cycle.	2
Understand the components of the universal systems model.	1
Adjust the input of a system to alter the output for greater efficiency.	1
Identify technology and their use in the engineering design process.	1
4. Total	25

The content mathematics standards that were addressed included graphing proportional relationships, interpreting the unit rate as the slope of the graph and comparing two different proportional relationships represented in different ways. The related science concepts included the relationship between force and motion and velocity. The pretest was administered prior to the first week of the study which started the instruction of the integrative STEM modules. For students who were absent, the test was administered before their first activity in the modules. The posttest was administered the week after the completion of the unit.

To measure student engagement, the Motivation and Engagement Scale (MES) Junior School (elementary/middle school) instrument developed by Martin (2005), was employed. The survey was chosen because of its wide use in the field. The purpose of the MES survey was to describe general academic engagement and motivation during the teaching and learning of the project-based, integrative STEM instructional unit. Internal consistency for the MES survey was tested and reported an acceptable Cronbach's alpha with a range of .70 - .87.

Martin (2014) states that the instrument measured students' motivation and engagement through three adaptive cognitive dimensions (booster thoughts), three adaptive behavioral dimensions (booster behaviors), three maladaptive cognitive dimensions (mufflers) and two maladaptive behavioral dimensions (guzzlers).

The boosters were self-belief, valuing of school, learning focus, persistence, planning and time management (Martin, 2014). Self-belief was the students' perception of themselves about their ability to perform well in school and meet challenges that they face. Learning focus refers to the students' ability to stay on task and focus on developed skills such as problem solving. Valuing of school relates to the students' idea of what they were learning in school was relevant and important. Planning and time management were the students' ability to plan their school work, organize their timetable for completion, and track their progress. Persistence was the ability for the students to persevere through challenging material.

The mufflers were failure avoidance, anxiety and uncertain control. Anxiety was the students feeling of nervousness and worry that they were not doing well with their schoolwork. Failure avoidance was the students' likelihood to avoid certain task due to their fear of failure. Students were uncertain in control when they did not understanding how to avoid from performing poorly.

The guzzlers were self-sabotage and disengagement. Self-sabotage referred to the students doing things that would reduce their chances of performing well. Disengagement referred to the students losing interest in their classwork and their feeling of giving up.

The raw scores of the MES survey were grouped into the 11 subscales. The scores for each subscale of motivation and engagement were compared meaningfully using descriptive statistics. Each subscale contained four questions. The subscales reflected a multidimensional model of motivation and engagement which included the following: self-belief, learning focus, valuing school, persistence, planning, study management, disengagement, self-sabotage, anxiety, failure avoidance and uncertain control. The measurement used a Likert scale response ranging from 1 (strongly disagree) to 5 (strongly agree). The items for the subscales failure avoidance, anxiety, uncertain control, self-sabotage and disengagement were reverse coded due to the negative phrasing of the items. Students were administered the MES survey right after the performance pretest during the week prior the instruction of the integrative STEM module. Students also completed the MES post survey after the Biomechanics academic performance posttest was completed one week after the completion of the unit.

Procedure

Schools were invited to participate in a teacher training grant focused on project-based learning using the engineering design cycle to integrate mathematics and science concepts. The schools that accepted the invitation assigned teachers to participate in the spring training. During the weeklong training, teachers engaged in the activities that were part of the project-based challenge in the integrative STEM module. Teachers received training on the operation and use of instructional technology such as the robotics kit, 3-D design software and printing. At the conclusion of the workshop, possible dates were scheduled for follow up professional development. The professional development was scheduled after the spring workshop and focused on providing a supplement to the training received in the spring. The curriculum was divided and trained in 3 sessions; 1) first and second weeks, 2) third and fourth weeks, 3) and fifth and sixth weeks. Teachers scheduled two dates for training on the first two thirds of the curriculum and implementation planning. The last date for professional development occurred during the second week of implementation. Student assent and consent forms were delivered to the teachers at the second meeting. The students completed both forms prior to the start of the study.

The study began during the instruction of unit 3-Equations and unit 4-Functions. These units are usually instructed the second quarter of the first semester. The teacher began implementation of the integrative STEM module the week after the pretest for performance and pre-survey for engagement were administered. Students were situated in the real life context of an engineering firm with 10 design groups. Students responded to a Request for Proposal (RFP), a current industry practice. The students were placed in groups of three to four members, per the teacher's discretion. Each group represented a design team for the engineering design company (class). The class was then instructed that each design team would create a solution. During the introduction the class was informed that each group would present their solution and subsequently, the engineering design company (class) would choose the best one. The class was informed that they would draft a unified response to the RFP. Along with the introduction to the RFP, the students identified criteria and constraints of the challenge and began preliminary research needed for the solution to the challenge. The researcher observed each class (mathematics and science) twice per week during the study. The study concluded with the module's final activity which included each group's final presentation. The administration of the posttest and MES survey occurred the week after the completion of the unit. During the last week of the study, seven interviews were conducted with students chosen randomly from each of the two mathematics classes. A number generator was used to select 7 students by the last four digits of their student number. The interviews were scheduled at an available time during school for 45 minutes. At the completion of the final day of the module, the teacher submitted to the researcher the posttest, engineering notebooks and artifacts.

Data Management Plan

As mentioned earlier, Yin (2014) stated one of the four principles of data collection referred to the development of a database to manage the data. Yin (2014) refers to the data being organized into an orderly compilation. The raw data collected were sectioned into three categories including paper, digital and artifacts. All data collected was managed and stored in a manner where each individual's data were matched and kept with non-identifiable demarcation. All paper-based data was filed and stored in a locked cabinet. The digital data, including videos, photographs, audio recordings and related transcripts, were stored on an external digital storage device. The device was stored in a locked cabinet. The artifacts collected, including the engineering notebooks, graphs and prototypes, were collected and stored in a locked storage cabinet.

Data Analysis

A combination of deductive and inductive approaches was employed to perform the study's analysis of the qualitative and quantitative data. The primary unit of analysis was the student learning behavior and performance as they engaged in the integrative STEM instructional model using robotics, 3-D design and printing in two eighth grade mathematics classes. Student behavior was investigated as they assumed the role of engineers in an engineering firm responding to a Request for Proposal (RFP). Students were observed as they entered into this situated context as apprentices, making thinking visible by collaboratively participating as a community of practice in an engineering group inside the firm. Developing solutions for the engineering design challenge (Figure 4).

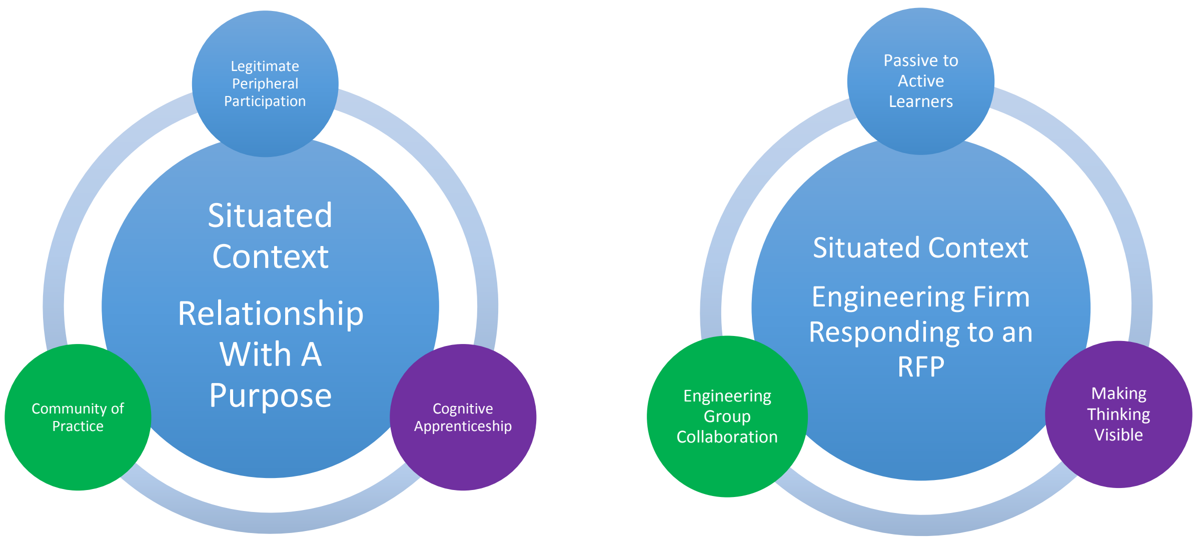


Figure 4. Concept Map Linking Study Design to Situated Cognition Framework.

To analyze the qualitative data, explanation-building techniques were used to investigate the teaching and learning of the project-based integrative STEM instructional unit. Paired sample *t*-tests to analyze the quantitative data collected. Yin (2014) affirms that the collection of data from multiple sources aids in the triangulation of data. Denzin (2012) offers methodological triangulation as a manner of including quantitative data analysis in case study. Both qualitative and quantitative analysis techniques will be described further.

Qualitative Data Analysis

To analyze the qualitative data, an inductive strategy using an explanation-building technique was employed to investigate the teaching and learning of the project-based integrative STEM instructional unit. Yin (2014) presents four general strategies for the analysis of the data collected; (1) relying on theoretical propositions, (2) working from the ground up (3) developing a case description and (4) developing rival explanations. Yin (2014) characterizes the strategy of working from the ground up as an inductive approach that allows themes and concepts to emerge during the analysis. Kohlbacher (2005) further describes the inductive approach as the collection of data in the beginning of the study then moving to general propositions. After a substantial amount of data was collected, an inspection of the data was performed to look for materialized patterns. The aim was to explore the nature of integrative STEM teaching and learning then presenting the themes that addressed the research questions. Yin (2014) maintains that using the inductive strategy employs some aspects of grounded theory that is relevant to all case studies. Yin (2014) claims that this allows the ability to explore the qualitative data to explain and give reasons why an event is happening.

Transcriptions from semi-structured interviews and observations were analyzed using qualitative techniques. I used the verbatim transcription technique to transcribe the interview. After browsing through the transcripts, I made note of my initial impressions. After my initial impressions were noted, I read the transcription carefully and used coding techniques developed by Saldana (2012) to locate distinct concepts and categories in the data. Relevant words and phrases that described the student's engagement and identified factors of motivation in the learning process were noted. Themes of critical thinking and understanding of the concepts taught were highlighted in the coding. Saldana (2012) claims that the primary goal for the researcher is to find patterns of action and consistencies. After a review of the initial codes were made, I used pattern coding to employ a directed examination of the themes determined from the first analysis of the transcriptions to insure that the important aspects have been identified.

Artifacts such as the engineering notebooks, prototypes and image-based data were analyzed using visual content analysis. Rose (2011) argues that there are four steps to visual content analysis: 1) finding content that is representative of the research question, 2) choosing a manner of sampling, 3) development of coding categories per the research question and 4) analysis done by exploring the relations between the coding categories. In the artifacts, evidence and characteristics of engagement and problem solving were identified. Student notes, drawings, and data collection entries in the engineering notebooks were coded similarly to the classroom observations and interviews. Coding was done to identify and examine patterns that emerged. Photographs of students immersed in activity were examined for engagement characteristics, which were defined and coded by level of participation and involvement. Visual content analysis was interpretive in the efforts of exploring these characteristics of integrative STEM teaching and learning. Representation of the students' activity was addressed by observing the manner that the participants wanted to be perceived in the pictures. The manner that the students present themselves in front of the camera is relevant data to be considered (Gibson, 2005). Coding was done to account for the occurrence of particular characteristics. The coding process was used to triangulate the physical data with other evidence collected.

Quantitative Data Analysis

To analyze the quantitative data a deductive approach was used to build a complete understanding of the teaching and learning of the project-based integrative STEM instructional unit. The pre/post tests employed to measure performance and engagement were analyzed using paired sample *t*-tests to aid in the triangulation of the data analysis. Paired sample *t*-tests compared the means from the performance pretest/posttest and the engagement pretest/posttest. The null hypothesis for the performance paired sample *t*-test stated that there is no difference in the means of the pretest and posttest administered. For the engagement pretest/posttest, the null hypotheses stated that there is no difference in the mean scores for each subscale of the engagement pretest and posttest.

Cronbach's alpha was used as a measure internal consistency of the academic test and the motivation and engagement scale survey to measure internal consistency of both instruments. The analysis of the coefficients informed the researcher whether the test scores were strongly related. The developer of the Motivation and Engagement Scale survey used exploratory factor analyses techniques to test validity on 44 items of the survey (Fredricks, 2012). Confirmatory factor analysis was conducted to test the fit of the booster cognitions, booster behaviors, mufflers and guzzlers. The analysis yielded an excellent fit to the data (χ^2=3,197.18, *df*= 886, CFI=0.98, RMSEA=0.046). The findings of the analysis resulted in the 11 sub scales of the survey.

Validity and Reliability

Qualitative Data

Yin (2014) expounds that triangulation strengthens the reliability and validity when the evidence is gathered from a variety of sources. The convergence of this data aided in the construction of validity for the study. Collecting from the various sources mentioned addressed the validity. Yin (2014) holds that maintaining a chain of evidence increases the construct validity of a procedure. A chain of evidence was maintained to insure that the evidence collected was accurate and consistent with the protocols and procedures.

Yin (2014) maintains that internal validity is a test needed for explanatory case studies where causality is reported. The research design of this case study was exploratory in nature. Yin (2014) states that internal validity is not a concern of exploratory case study. The research questions were looking to explore the situational factors and use of project-based, integrative STEM modules influence on student performance and engagement.

Yin (2014) states that external validity tests whether a study's findings can be generalized. Since this exploratory case study has an interest in giving an overview of what the effects were on performance and engagement when using the integrative STEM curriculum, the nature of the research question hinders the need to seek generalizations. Yin (2014) also affirms that reliability can be achieved by minimizing error in the study. The database of evidence and protocols in collecting and managing data were addressed with this concern.

Quantitative Data

Trochim (2006) argues that in a single case design there are four threats to internal validity concerning pre/post test data: 1) history, 2) maturation, 3) testing and 4) instrumentation. The protection against these threats were taken through the analysis of the pre/post data in concert with the analysis of the other data sources. The tests and questionnaires were tested for internal consistency using Cronbach's alpha measure.

Confidentiality and Ethics

The last principle of data collection expressed by Yin (2014) says that precautions should be taken with the collection, storage and usage of data. Protection of participants is a central principle in research. All efforts were taken to insure that harm and danger was non-existent in the study. Several main issues were addressed concerning the participant's engagement with the study. Participant privacy and safety was guarded and protected using protocols that do not identify the participant's responses or artifacts to an identifiable person.

IRB approval was obtained to maintain the privacy or confidentiality of the participants. Informed consent and assent was obtained prior to the study. Instructional activities were designed with an honest assessment of safety concerns identified and proper procedures implemented to insure safety. The reporting of findings was done ethically and accurately to protect the participants and the community in which the investigation was conducted.

Limitations of the Study

Berg (2004) states that a single case study has the limitations of lacking methodological rigor, researcher subjectivity and external validity. Berg (2004) further states that the lack of systemic procedures for doing case study has been a concern, especially in regards to methodology. Flyvbjerg (2006) adds that there is a misunderstanding that a generalization on the basis of an individual case will not contribute to scientific development. The audience of this research will look for a cookie cutter process to implement the model as a way to produce better STEM students. It is the researcher's intent not to provide a cookie cutter plan but to provide and expand generalized theories that can inform decisions made on the development of similar STEM instructional models. It is the aim to develop context-dependent knowledge about learning which is needed to move practitioners to experts.

Another limitation to the study included the difficulty in measuring engagement. Fredricks et al. (2012) explain that although engagement has been of interest to the education arena, just like the idea of STEM education having many variations to its definition, engagement has many conceptual variations as well. With the many different constructs available, having approached the study with a broad understanding of engagement, aided in addressing the limitations. Instruments used have a measure of limitation that is associated with them. Instrumentations used in research may force respondents into particular responses. Forcing respondents to a certain path of answers may inhibit the study and falsely encourage conclusions that are incorrect.

There are possible limitations with the fidelity of implementation with the curriculum. O'Donnell (2008) defines "fidelity of implementation" as the extent and manner to which an intervention was implemented as originally planned. The study considered the intent and manner of the teacher's instruction of the engineering design cycle and the use of 3-D printing. The degree of enactment in perspective to the designed and intended enactment was considered. O'Donnell (2008) also claims that fidelity can reveal important information regarding how well the curriculum is taught. If the fidelity is hard to achieve, then it is difficult to explore the effectiveness of integrative STEM. Insuring fidelity begins with the development and training of the instructor before implementation. After the formal professional development activities were facilitated, communication by email and face-to-face meetings took place in order to prepare the teacher to enact the curriculum as intended. These steps were documented and recorded for consideration in the study.

CHAPTER 4

Data Analysis and Results

The purpose of this study was to investigate and describe the effects of using project-based integrative STEM modules on eighth grade students' performance and engagement. The integrative STEM curriculum was implemented in two randomly selected eighth grade mathematics classes and their corresponding eight grade science classes in an urban middle school located in a major southeastern U.S. city.

This chapter examined the findings from the sample and subsample that were selected from these classes. The quantitative sample included 54 students selected from both mathematics classes and the qualitative subsample included 7 students selected randomly from each of the two mathematics classes. The students will be mentioned by number. The case study addressed the following questions:

1. What is the effect of using project-based, integrative STEM modules on 8th grade student performance and engagement in learning a unit on linear functions?
2. What STEM-related situational factors contribute to 8th grade students' success in learning using project based, integrative STEM modules?

Quantitative and qualitative data were collected to address the concerns of the research questions. The quantitative data collected included students' responses to pre/post tests to measure performance and a motivation and engagement survey to measure engagement. The qualitative data collected consisted of semi-structured interviews, observations and student artifacts. Artifacts included entries and notes made in the students' engineering notebook, manufactured prototypes and photographs. Following, I have outlined the analysis techniques and results for the quantitative and qualitative data respectively. After the discussion of the techniques and results, a summary will be provided.

Quantitative Data Analysis

Analysis Techniques

The paired sample *t*-test was employed to answer research question 1. The null hypothesis for performance stated that there is no difference in the means of the pretest and posttest administered. For engagement pretest/posttest scores, the null hypotheses stated that there is no difference in the mean scores between the two tests. A two-tailed test using significance level of .05 was used for both. Paired sample *t*-test assumptions were tested with descriptive methods and data management verification. The results informed the proper use of the data. The following will discuss the result for achievement and then engagement.

Achievement

Testing Assumptions. Minium and Clark (1982) state that all statistical tests, such as the *t*-test, operate under certain assumptions to produce valid results. The first assumption states that the distribution should be measured on a continuous scale. Examples of this would include time, intelligence quotient test scores or exam scores. The second assumption calls for the data to come from two related groups and reside in both groups as well. For example, if you are measuring 10 individual's performance on a timed run, then you will measure the time for the second run from the same 10 individuals. The first two assumptions were verified through the management of the data. The scores from both pre/post tests were continuous and fromed matched pairs. Minium and Clark (1982) offers that the third assumption states that there should be no significant outliers in the differences between the two related groups. The presence of outliers negatively affects the results of the paired sample *t*-test. The check for outliers was made by inspecting a boxplot for both the pre/posttests (Figure 5).

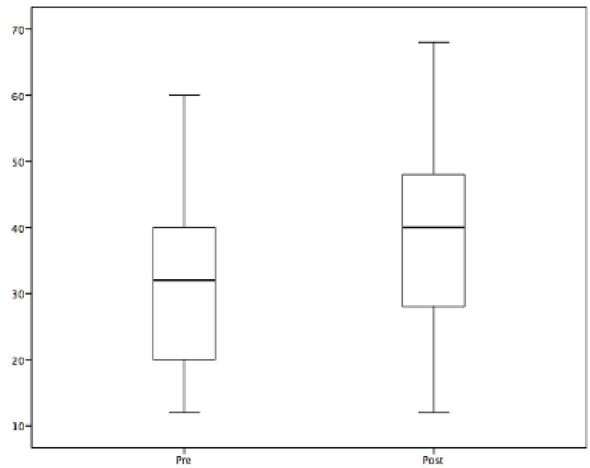


Figure 5. Pre/Post Test Concepts and Number of Items per Concept.

The final assumption requiring testing is that the two related groups should be normally distributed. The assumptions were that if the sample is of normal shape, then the population of which it was obtained is of normal shape. If the results of the test show that it is not a normal shape, then non para-metric tests would need to be employed. The scores of the achievement pretest were normally distributed with a skewness of 0.310 and kurtosis of -0.610. The scores of the achievement posttest were normaly distributed with a skewness of -0.143 and kurtosis of -0.234 (Table 3).

Table 3

Skewness and Kurtosis Statistics for the Achievement Pre/Posttest

	Skewness	Kurtosis
Achievement Pretest	0.310	-0.610
Achievement Posttest	-0.143	-0.234

Reliability Analysis. The reliability was used to determine and confirm the internal consistency of the items on the pre/post tests. Reliability provides a measure of the extent to which a score reflects random measurement error and is a precursor to test validity. Cronbach's alpha provides a measure of the extent to which the items on a test provided consistent information with regards to the students' mastery of that particular domain. Cronbach's alpha for the pretest was found to be reliable (10 items; $\alpha = .843$). Cronbach's alpha for the posttest was found to be reliable (10 items; $\alpha = .839$).

Paired sample *t*-test. In regards to achievement, the results indicated that the mean of the posttest ($M = 3.926$, $SD = 1.358$) was significantly greater than the mean of the pretest ($M = 3.204$, $SD = 1.294$) where $t(df = 53) = 5.646$ and $p < .001$. The results indicated that there was a statistically significant difference in achievement between the pretest and posttest.

Engagement

Testing Assumptions. As stated earlier, parametric statistics have assumptions which must be met and tested. There were four assumptions be tested for the paired sample *t*-test performed for the MES survey. The first two assumptions were tested in the same manner as was done for the pre/posttests for achievement. It was observed that the responses from the MES survey were continuous and from matched pairs. DeWinter and Dodou (2010) state that there have been debates and disagreements on whether five-point Likert data should be analyzed using parametric statistics or nonparametric statistics. Part of the issue deals with the assumption of normality for the data. By studying various possible distributions from 5-point Likert item surveys, the *t*-test was found to be accepted and favored. In regards to the MES presurvey, for the 11 subscales, each were normally distributed with skewness of a range -1.210 to 0.231 and kurtosis of a range -1.355 to 1.553 (Table 4). In regards to the MES postsurvey, four out of the

11 subscales were non-normal: (1) self-belief, (2) valuing school, (3) planning, and (4) uncertain control (Table 4). The responses on the postsurvey for the subscale self-belief had a skewness of 3.332 and kurtosis of 15.049. The responses for valuing school had a skewness of -1.336 and kurtosis of 3.191. The responses for planning had a skewness of -1.032 and kurtosis of 2.305. The last non normal subscale, uncertain control had a skewness of -1.140 and kurtosis of 2.049.

Seven subscales on the postsurvey were normal: (1) learning focus, (2) study management, (3) persistence, (4) anxiety, (5) failure avoidance, (6) self-sabotage, and (7) disengagement. The responses for theses subscales had a skewness from -1.543 to 0.163 and kurtosis from -0.980 to 1.355 (Table 4).

Table 4

Skewness and Kurtosis Statistics for the MES Survey Subscales

	Pretest		Posttest	
	Skewness	Kurtosis	Skewness	Kurtosis
Self-belief	−1.045	0.306	−3.332	15.049
Valuing school	−1.210	1.553	−1.336	3.191
Learning focus	−1.174	0.609	−1.032	0.450
Planning	−0.158	-0.877	−1.032	2.305
Study management	−0.373	-0.679	−1.180	1.050
Persistence	−0.929	0.914	−0.618	0.369
Anxiety	−0.042	-0.730	0.163	-0.657
Failure avoidance	0.231	-1.355	−0.031	-0.980
Uncertain control	−0.313	-0.287	−1.140	2.049
Self-sabotage	−0.777	.057	−1.543	1.355
Disengagement	−0.397	-1.035	−0.824	0.128

Reliability Analysis. Cronbach's alpha was used to determine and confirm the internal consistency of the items on the pre/post surveys. Cronbach's alpha for the pre-survey was found to be reliable (44 items; α = ,787). Cronbach's alpha for the post-survey was found to be reliable (44 items; α = .773).

Paired sample *t*-test. To compare the pre/post survey for the motivation and engagement subscales, a paired sample *t*-test was employed for each subscale using the raw scores. The negative subscales were reverse coded, as described in the previous chapter.

In regards to the self-belief subscale, the results indicated that the mean of the post-survey (M = 4.482, SD = 0.840) was not significantly greater than the mean of the pre-survey (M = 4.333, SD = 0.657), where $t(df = 53) = 0.974$ and $p = .334$.

In regards to the valuing school subscale, the results indicated that the mean of the post-survey (M = 4.167, SD = 0.634) was not significantly greater than the mean of the pre-survey (M = 4.324, SD = 0.732), where $t(df = 53) = -1.195$ and $p = .237$.

In regards to the learning focus subscale, the results indicated that the mean of the post-survey (M = 4.412, SD = 0.643) was not significantly greater than the mean of the pre-survey (M = 4.380, SD = 0.702), where $t(df = 53) = 0.240$ and $p = .811$.

In regards to the planning subscale, the results indicated that the mean of the post-survey (M = 3.551, SD = 0.957) was not significantly greater than the mean of the pre-survey (M = 3.657, SD = 0.908) where $t(df = 53) = -0.583$ and $p = .562$.

In regards to the study management subscale, the results indicated that the mean of the post-survey (M = 3.819, SD = 0.952) was not significantly greater than the mean of the pre-survey (M = 3.940, SD = 0.692) where $t(df = 53) = -0.710$ and $p = .481$.

In regards to the persistence subscale, the results indicated that the mean of the post-survey (M = 3.921, SD = 0.718) was not significantly greater than the mean of the pre-survey (M = 3.889, SD = 0.691) where $t(df = 53) = 0.246$ and $p = .806$.

In regards to the anxiety subscale, the results indicated that the mean of the post-survey (M = 2.468, SD = 1.047) was not significantly greater than the mean of the pre-survey (M = 2.380, SD = 0.775) where $t(df = 53) = 0.498$ and $p = .620$.

In regards to the failure avoidance subscale, the results indicated that the mean of the post-survey (M = 3.199, SD = 1.224) was significantly greater than the mean of the pre-survey (M = 2.611, SD = 1.090) where $t(df = 53) = 2.718$ and $p = .009$.

In regards to the uncertain control subscale, the results indicated that the mean of the post-survey (M = 3.773, SD = 0.967) was not significantly greater than the mean of the pre-survey (M = 3.569, SD = 0.967) where $t(df = 53) = 1.236$ and $p = .222$.

In regards to the self-sabotage subscale, the results indicated that the mean of the post-survey (M = 4.208, SD = 1.011) was significantly greater than the mean of the pre-survey (M = 3.792, SD = 1.002) where $t(df=53) = 2.165$ and $p = .035$.

In regards to the disengagement subscale, the results indicated that the mean of the post-survey (M = 3.954, SD = 0.894) was not significantly greater than the mean of the pre-survey (M = 3.958, SD = 0.848) where $t(df = 53) = -0.031$ and $p = .976$.

The results indicated that for the motivation and engagement 11 subscales there were only significant differences in the failure avoidance and self-sabotage subscale.

Qualitative Data Analysis

Method of Analysis: Coding

Miles, Hubberman and Saldana (2013) offer that one of the strengths of qualitative data is the manner of understanding what real life is through observing natural and regularly occurring events. Understanding the unit of analysis, the student behavior and performance as they engage in a project-based robotics and engineering design module, attention to the analysis of the qualitative data must start with an analytic strategy (Yin, 2014). Collecting multiple data points occurring in a complex, real world context requires a coordination to search for patterns, categories and themes. Data collected to examine the primary unit of analysis of student behavior included classroom observations, semi-structure interviews and researcher's notes.

Using a four step process outlined by Saldana (2009), the descriptions, codes and categories were extracted to find the emerging themes throughout the analysis of the data. By the researcher's and teacher's interpretation and reflections, transcribed interviews, observations, and students' engineering notebook were hand coded to describe indicators and develop categories. Observation protocols and researcher reflections were used to identify indicators of engagement during both student specific and group specific actions. Indicators included the following: (1) student engagement in discussion with the teacher during whole class instruction, (2) student engagement and behavior during whole class instruction, (3) physical position during whole class instruction, (4) the students individual actions in response to the challenge's context, (5) the students interaction with group members, (6) students' engagement in discussions, (7) the students use of STEM related terms and phrases (8) the students group interaction during experimentation and testing, (9) the groups formation of social structures and norms created to regulate and organize group behavior, (10) groups' negotiating and collaborating, (11) the groups formation of STEM related and challenge specific language, (12) group's formation and construction of meaning, (13) the use of the constructed meaning, (15) students' behavior during the interaction with robotics and 3-D printing, (16) the group behavior using robotics and 3-D printing during the problem solving process and (17) the class discussion and negotiation during solution presentation and selection. With these indicators in mind, I was guided through the three step process offered by Saldana (2009).

Step 1: Initial coding. Saldana (2009) defines a code as a word or phrase that gives some connective characteristic that summarized or assigned a characteristic to a particular piece of collected qualitative data in writing or in imagery. Yin (2014) suggests that the analysis of the data from an exploratory case study be continual and ongoing. I started the coding process as soon as data was collected. Reviewing the data at this level throughout the study allowed for the formation of codes to explore many facets of the unit of analysis. The following 33 codes were identified by hand not necessarily in order of identification: (1) activity transfer, (2) reading and writing, (3) perseverance, (4) decision making, (5) technology frustration, (6) classroom discussion, (7) project-based learning, (8) career goals, (9) subject integration, (10) student perception of project-based learning, (11) student self-perception, (12) application of concepts, (13) student and robot relationship, (14) student thinking, (15) use of scientific ideas, (16) student inquiry, (17) group thinking, (18) group collaboration, (19) STEM language, (20) use of technology, (21) knowledge acquisition, (22) assimilation, (23) application, (24) adaptation, (25) classroom environment, (26) mathematics computation, (27) engineering design, (28) artistic, (29) data representation, (30) data visualization, (31) skills transfer, and (32) emotional.

Step 2: Descriptive coding. As recommended by Miles, Hubberman and Saldana (2013), I refined the coding using descriptive phrases or terms to collapse, expand and revise the codes. Also, as Saldana (2009) suggests, descriptive coding works well when you have a variety forms of data such as interview transcripts, field notes and artifacts. Since the research questions are looking into what effects are present, descriptive coding affords the approach the ability to explore these items.

Step 3: Pattern coding. Saldana (2009) states that pattern coding is a viable step in the cycle of initial-descriptive coding. Examination of the codes identified similarities between them. The similar codes were grouped together based on their commonalities and labeled. The label for each of the categories showed a deeper meaning of the relationship between the codes and provided an inspiration for the subsequent theme that emerged. Pattern coding allowed a way to group the similar codes into categories.

Step 4: Emerging Themes. The categories were examined for relationship and commonality to provide deeper context. The purpose of pattern coding is to be a catalyst for themes to emerge. The themes emerged by identifying the commonalities of their relationship, function or patterns. During the movement through the coding cycle, six emerging themes developed and are presented in Table 5. The themes were partitioned by effects and factors.

Table 5

Categories to Themes

Categories	Themes
1. Physical interaction with Robot 1. Assigning robot human characteristics 1. Robot's Human Characteristics 1. Student extension of self	1. The developing anthropomorphic relationship with the robot enhanced student engagement.
2. Student operation of the robot 2. Experimentation 2. Student motion and action 2. Application of concepts 2. Manufacturing	2. Purposeful and intentional student physical action supported meaningful engagement in the design environment.
3.Peer discussion 3. Peer decision making 3. Role assumption/assignment 3. Leadership/Accountability 3. Construction of meaning	3. Purposeful collaboration promotes engagement through the construction of meaning and interaction.
4. Adapting and changing of learner role 4.Superficial to meaningful learning 4. Student inquiry 4. Ownership/leadership	4. A learning environment that has transformative learning potential fosters student success.
5. Innovation 5. Group Collaboration 5. Modeling mathematically 5. Willingness to create 5. Student perseverance	5. Learning experiences underpinned by design thinking lead to positive student outcomes.
6. Contextual ownership 6. Acknowledgement of skills 6. Emotional connectivity	6. Contextual relevance is enhanced when students have freedom to design their own learning journey.

Emerging Findings

Six themes emerged as a result of data analysis providing evidence of effects and presence of situational factors that impacted student engagement during their journey through the integrative STEM robotics and engineering curriculum.

Effects on student engagement:

1. The developing anthropomorphic relationship with the robot enhanced student engagement.
2. Purposeful and intentional student physical action supported meaningful engagement in the design environment.
3. Purposeful collaboration promotes engagement through the construction of meaning and interaction.

STEM-situational factors contributing to students' success:

4. A learning environment that has transformative learning potential fosters student success.
5. Learning experiences underpinned by design thinking lead to positive student outcomes.
6. Contextual relevance is enhanced when students have freedom to design their own learning journey.

Effects on student engagement

Theme 1: The developing anthropomorphic relationship with the robot enhanced student engagement. Groom, Takayama, Ochi and Nass (2009) claim that robots may be responded to as an extension of oneself. When a student attributes behaviors and characteristics that they have to a non-human object or agent, such as a robot, it is referred to as anthropomorphism and regularly occurs in science education (Al-Balushi, 2013). During the first investigation, students were excited at the possibility of using the robots in class. Student #1 expressed her interest by questioning "Can we build one (robot) that moves like a man?" The nature of the question transfers human characteristics to the object of interest. Even though the project-based context described the modeling of an insect like robotic device, the students were intent with attaching human like behaviors and characteristics to the robot. As a result of the projection of human characteristics, the robots became a form of self-expression by the students (Catlin, 2012).

When performing tasks with the robot the students used the term “run” to mean operate. During an observation of the students conducting trials of the robot traversing a lined track to determine velocity during Investigation 4, Student #4 said, “Move, it’s my turn to run the robot.” The use of the term “run” is further correlated to human characteristics as Student #1 describes her enthusiasm for using robots. Student #1 mentioned “it was cool and then I got to see it (robot) run, run around and stuff” Her description of the way the robot was using its legs and the shape of its feet running around was similar to how she would describe a friend running around a playground or a field.

Other behaviors were acknowledged by the students as the robot moved from an extension of self to having its own human like presence. Korkmaz, Aultman, Ussta and Ozkaya (2014) state that as the novelty of using robots wears off, students begin to assign personalities to the robots to help with their understanding and guide them in their thinking. When describing the motion of the robot in Investigation 2 to determine the optimal gait, Student #3 was observed in a group discussion describing the robot’s motion as “the robot wasn’t stable, because it was going all across the paper.” Student #1 in an interview described the testing of the robot operation over different surfaces noticing “how the robot responds to different surfaces.” The word respond was used in the fashion of how someone would respond to the change in the weather.

As a result of giving the robot a personality, a relationship developed with the robot and the students. Student #3 in an interview noted how interesting it was to see the robot “interact with different surfaces.” The nature of this interaction is akin to their interaction with others in their class or school. Student #4 in an interview further described how the relationship developed with themselves and the robot. Student #4 explained that one of the differences between this activity and other activities done during the school year as such, "I never like got to actually work with a robot. It's interesting to see how it works and see how different things affect how it moves and what not." Working with the robot was said as though the student was working with a partner in class on an assignment or homework. Student #6 and her group appeared to accept it as one of their group members. The students invited their robot into their physical space as if the robot was a fellow classmate or friend. The acceptance of the robot into their community is evident as seen in Figure 6.

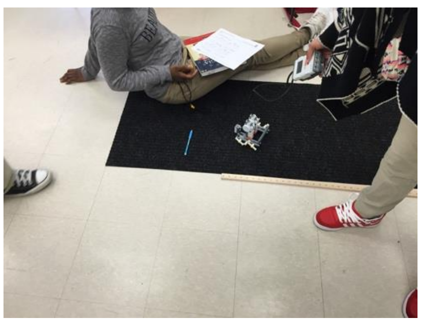


Figure 6. Students in Close of Proximity to the Robot During Testing

Theme 2: Purposeful and intentional student physical action supported meaningful engagement in the design environment. Embodied or extended cognition holds that cognitive processes are deeply rooted in the body's interactions with the world or environment (Wilson, 2002). The study exposed many instances of doing that are characterized by deeply rooted cognitive processes that give evidence to student engagement. During the first investigation, students were asked to review a Request for Proposal (RFP) and determine the criteria and constraints for the challenge. Students found it difficult at times to read the RFP and determine the essential parts needed to identify the criteria and constraints. These activities resembled aspects of a traditional class where the student participated in a reading and writing activity. Student #6 was observed in a whole class discussion regarding the identification of criteria and constraints to have said that “all the stuff in the middle (letter of response, testing documentation, daily log of work, presentation)” was required and could be considered criteria. Here stuff is said in a manner that devalues its presence and is mentioned as a matter of fact.

After determining the criteria and constraints, students were then assigned a robot. The students discussed optimal movement and were told that to begin understanding the motion, they were going to test different robots with different leg configurations. During the experimentation, the students were able to claim which robot leg configuration was the best after operating each robot with their respective leg configuration. It was observed that Student #2 during a group discussion offered that “the black robot moved in different directions.” During the subsequent whole class discussion, he extended the conversation by saying “the orange robot is most balanced but the green is the fastest.” By doing the activity, they were able to experience the motion and begin to develop understanding of what was happening.

During Investigation 3, after having determined the optimal leg configuration, students were tasked to observe the robot moving over different surfaces. The first activity engaged the students to experience and gain an experiential understanding of each of the surfaces. The Foot Friction Experiment has each student personally explore push, pull and friction with their feet. After completing the Foot Friction Experiment, Student #2 recorded his observations in his engineering notebook. The observations were written in bulleted form as seen in Figure 7. The observations used verb and action phrases recounting the student’s actual experience during the experimentation. The entry was completed without sentence structure and basic one-word description. Even with the simplicity of the description, the observation was rooted in movement. Student #6 recorded her observations for the same experiment using a sentence for each of the surfaces. She used the same type of descriptions but was very limited in her writing of the observation (Figure 8).

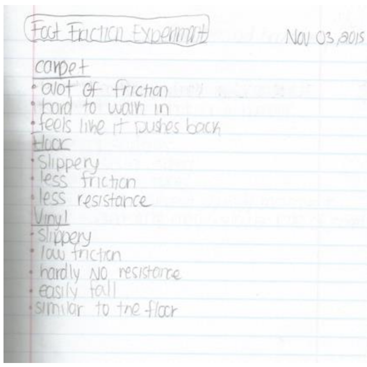

Foot Friction Experiment
Nov 03, 2015
carpet
• alot of friction
• hard to walk in
• feels like it pushes back
Floor
• Slippery
• less friction
• less resistance
Vinyl
• slippery
• low friction
• hardly no resistance
• easily fall
• similar to the floor

Figure 7. Student #2 Engineering Notebook Entry Foot Friction Experiment.

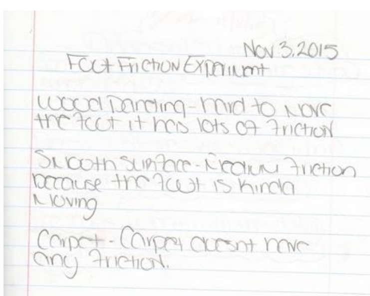

Nov 3, 2015
Foot Friction Experiment
Wood Danceing - hard to move the foot it has lots of friction
Smooth surface - Medium friction because the foot is kinda moving
Carpet - Carpet doesnt have any friction.

Figure 8. Student #6 Engineering Notebook Entry Foot Friction Experiment.

These observations described the action and reaction of Student #2 and Student #1 with the surfaces after completing the experiment. After completing the Foot Friction Experiment, the students performed similar experiments with the robots over the different surfaces. The students were asked to write their observations describing the movement of the robots over the different surfaces. When reminded to write their observations, Student #7 expressed to his group "I'm not writing, I'm doing the robot." He made his preference to "doing" clear when asked in an interview what part of the unit he liked least. He responded, "The worst part of the…it was probably the writing. I like writing but sometimes writing becomes boring." The expression "doing" shows the intentional action combining the movement of the robot with the movement of the student.

Student #4 engaged in a conversation with the teacher during the experimentation. In the group discussion, Student #4 said "The robot is slower on the carpet than on the vinyl." The teacher overhearing the statement, joined the discussion and asked, "How do you know?" Student #4 replied, "The velocity for the vinyl is 4.5 and the velocity for the carpet is 3.5." From the manipulation of the robot over different surfaces, Student #4 is beginning to form his understanding of speed and velocity. As student are engaged in the context of the challenge, more cognitive decisions are made to purposefully overcome any challenges they face in the design process. The students in their groups were making sense of their new experiences through their interaction physically with their robot. Notice in Figures 9 and 10, all members of the groups containing Student #1 and Student #7 are in action as each has assumed a role in the operation of the robot.

Figure 9. Student #1 Testing the Robot Operating on a Vinyl Surface.

Figure 10. Student #7 Testing the Robot Operating On a Tile Surface.

Investigation 4 had them use the data logging feature of the robot to produce graphs to record the robot's motion. During a whole class instruction, Student #3 asked, "Can we run the robot again?" A member of his group joined him after he performed another trial to analyze the data from the trial. The group member pointed to the data and said "I think this is when it runs over the black lines." Here, the students are forming understanding of action graphically. Student #3 replied, "So since there are six lines there should be six spikes…1, 2, 3, 4, 5, 6 (counting each one). So now we look at the space between each?" See Figure 11 for their data using the data logging feature of the NXT.

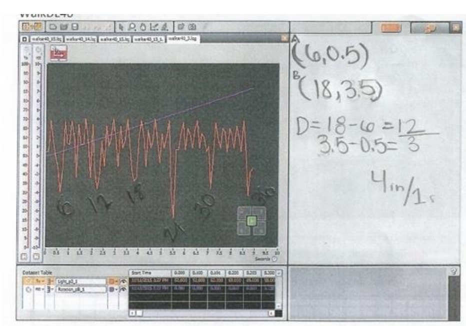
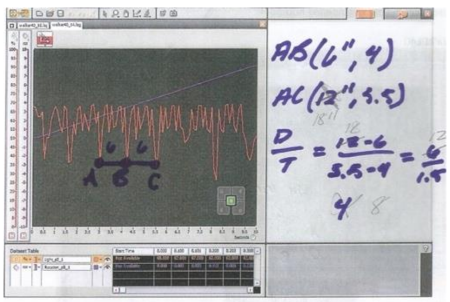


Figure 11. Screenshot NXT Data Logging Student #3's Engineering Notebook.

The entire system becomes part of the cognitive process. During the interview with Student #3, I asked him what was the impact of collecting the data from the robot using the data logging feature. I also asked him about his experience translating the data to a coordinate graph.

I asked him if it helped him with the understanding of slope and velocity. Student #3 answered, “I liked it because it helped the group like (make) a connection, like almost like connected the hands on activity to the actual calculations.”

Moreover, students began to relate the action of operating the robot to calculating slope and velocity. Students collaboratively formed the meaning of relating the data logging graph to data represented on a coordinate plane (Figure 12 and 13).



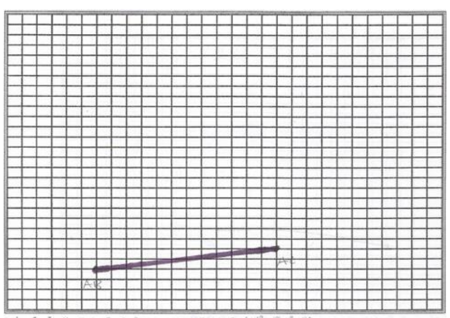


Figure 12. Screenshot NXT Data Logging Student #3’s Engineering Notebook.

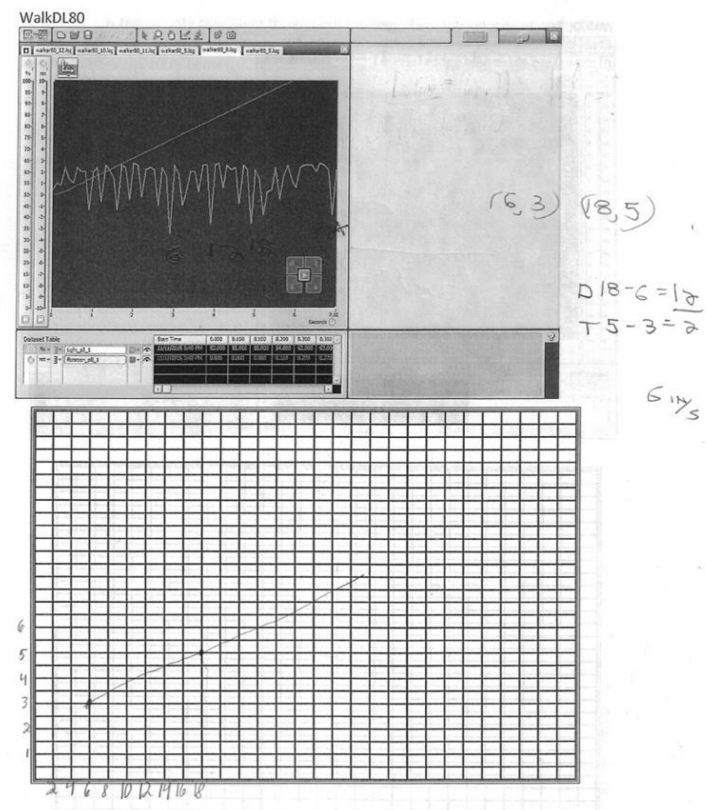


Figure 13. Screenshot NXT Data Logging Student #5's Engineering Notebook.

Investigations 6 and 7 had the students design a procedure to test their solutions and determine what improvements had to be made. The students now were in control of their action and their learning. Student #6 felt so excited that she wanted to test the feet out herself (Figure 14). Student #3, while engaging with the group during the creation of their procedure to test their feet said, "I'd rather find the distance and time myself than use the light sensor." Finding the distance and the time involved physical action of the students. In Figure 15, Student #5 suggested to his group that "(they) should measure the distance and time, calculate velocity and then observe how straight it traveled."

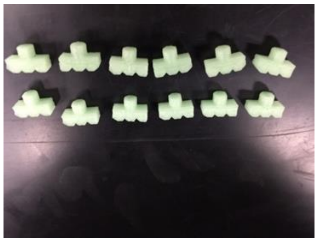


Figure 14. Student #6 Printed Feet.

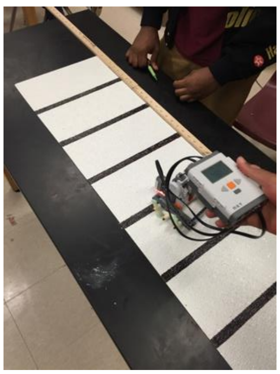


Figure 15. Student #5 Testing Printed Feet

I asked the students during interviews if the activities increased their interest in STEM and if it had an impact on how they formulated their understanding. Student #1 offered, “I think so, because it’s not like…We’re not just like re…We’re not just like…Not that reading is bad or anything, but we’re not just like reading off a packet or whatever filling stuff in, we actually get to work with it, see actually visually see how it operates and stuff…Yeah, yeah.” She also said that, “It’s (integrative STEM curriculum) more interactive and you actually get a chance to actually do something rather than just sitting there and just filling…basically filling out information.” Student #8 answered, “I liked it, I mean because it was more…It was better because you got to really do it. Instead of like someone else doing it you really got to do it and understand it yourself.” Student #2 echoes the comments by saying, “It was kind of different but it was like in a way…It was kind of helpful because a lot of times, well math is like…It’s kind of like you follow this set of rules, this process, and you have to get like this certain answer, but it (integrative STEM curriculum) helps when you can like do experiments and when you make mistakes you can see kind of how it would lead you to get this actual process and how you would actually get the answer that you're supposed to get or something like that."

Theme 3: Purposeful collaboration promotes engagement through the construction of meaning and interaction. According to Wenger (1998) belonging to a Community of Practice displays aspects of engagement. Engagement can be observed while the students interact with their groups during discussion, collective thinking, and collaborative meaning making. While interviewing Student #1, I asked her to describe the discussions that were occurring in the group. Student #1 replied, "Okay, so one, we were trying to decide how, like what kind of pattern would be better, like if we should do for the foot, if we should use like a spike, like more like spikes, or if we should use like round to see which one would probably maybe grip the surface better." From previous experimentation, the students have determined that when the robot is operated at a higher power, the robot begins to loose traction. Figure 16 shows the drafted designs from student #1 that were the subject of this discussion.

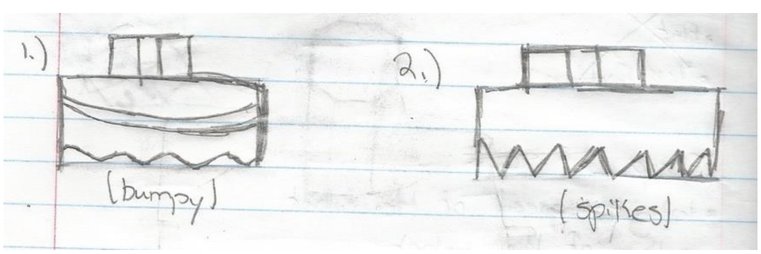


Figure 16. Student #1 Bumpy Foot Design and Spike Foot Design.

These two design depict their understanding for solving the problem of having just the right amount of friction by designing the foot's surface in a way that would apply the needed amount of friction. This description details some of the collaborative thinking and collaborative cognitive processes that were used to make decisions regarding the design process. During group discussions, the group recorded ideas that group members had. These ideas were recorded in their engineering notebook in Figure 17.

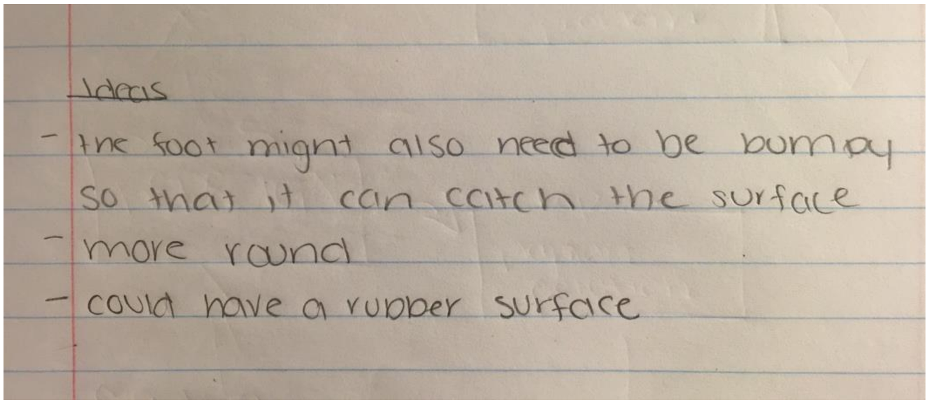


Figure 17. Student #4 Engineering Notebook Entry Foot-Like Device Ideas.

The many engineering groups in the class (engineering firm), took advantage of the opportunity to create and make meaning by analyzing graphical representation and relate them to science and mathematics concepts. It was observed in a group discussion that Student #4, while inspecting the data logging graph from the LEGO Mindstorms NXT data logging software that "one has more spikes than that one (Figure 18)." One group member replied pointing to the graph, "I think this is when it runs over the black line." Student #4 replied "So, since there are six lines there should be six spike…1, 2, 3, 4, 5, 6. So now we look at the space between each?" The students are making the meaning that for this activity, space between each spike relates to the time that the robot took to get from one line to the next. The group came to the conclusion that if the space was wider than other spaces on the graph this showed either a lack of friction or presence of unbalanced motion (Figure 18). Collaboratively the group members correlated the lack of friction using data visualization to the velocity of the robot.

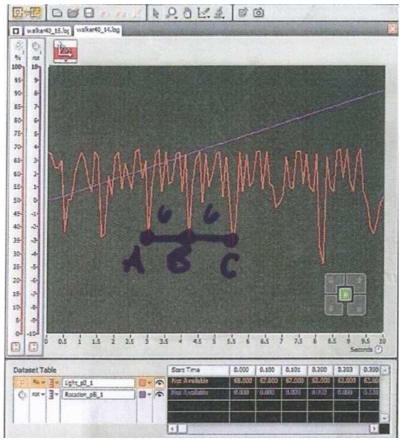


Figure 18. Data Logging Graph from The Engineering Notebook.

Group collaboration allows for the formation of practices and social structures that the students participate in as a unit. As students begin to share their thinking with each other, they are forming standards and expectation that allow them to come to a group decision on how the solution should be design and crafted. Student #6, when asked in an interview if working in groups was helpful, she answered, “I like that (working in groups) a lot because you get to see how different people think and how would they think about doing it.” The joining of ideas and thinking processes allows for the group to devise a plan of action that uses the agreed parts of everyone’s thinking. The students negotiate within the group what is needed to meet the criteria of the design challenge

I asked Student #2 how he liked working in groups he said, “With working in groups it’s kind of easier to tell where you go wrong. Like math, if we’re doing a process and I kind of, if I forget a step or do a step wrong, because there are other people in the group with me it’s easier to…I can talk to them about it and they can show me exactly where, what, like where I went wrong and what happened so that I can kind of bring it back in and I can do it later on my own.” Collaboration allows each of the group members to capitalize on each other’s suggestions, skills and ideas (Heidrich, Kasa, Shu & Chandler, 2015). As group members develop skills and become more experienced, they can offer help and expertise to others that are not as developed. So, in this community the students are assuming many roles at the same time. They can be less experienced in one manner and experienced in another.

STEM-situational factors contributing to students' success

Theme 4: A learning environment that has transformative learning potential fosters student success. Mezirow (2000) defines transformative learning as the process where frames of reference, which were taken for granted, are changed to make them more critical, open, reflective and inclusive. Transformative learning was designed to be used in adult education but has made it way to the middle school level. Elsey (2011) claims that transformative learning at the middle school level promotes student responsibility, student critical reflection, students change in perception as a learner. Transformative learning provides a self-directed and innovative learning environment particularly in STEM concepts where students can take control of their learning and use the skills they have to achieve the goal of the activities. Students' fear of failure is lessening and students are empowered in their new role.

To explore the STEM-situational factors data was collected with the intention of looking at the impact made on student success throughout the 6 investigations. As mentioned before, the module started with the introduction to the challenge in Investigation 2. I asked Student #2 if the context set by the teacher that situated the class as an engineering firm responding to a Request for Proposal (RFP) was an instructional strategy that he liked or disliked. Student #2's response was, "I kind of, I like it because it's like when you give situations, when you're given situations like that it helps you see that like…It helps you bring it in to all the things that you do in everyday life, like in a lot of other problems, maybe like personal problems you kind of sit with a problem and situate it and then it helps you bring out like the desired kind of outcome that you want." In mentioning that the end result is the "outcome that you want" shows the level of ownership taken by the student. In context of the RFP, the student starts to develop the type of information that they want to acquire and in turn plan what the students want to do with that information to get the desired result and respond to the RFP. Taking ownership of the learning leads to an increase of social awareness, and how the skills learned can breed a connection between themselves and the world around them. Student #7's response to the same question was, "Yes, I liked it because it made you feel like…It made it feel more realistic and what you were doing would really help something, like an actual problem."

Student #3 further described the impact of the context of the challenge and made a comparison to previous experiences, "…usually in Math we just sit around, the teacher will talk, we take notes and have to study and this we interact with stuff and it makes it interesting." The accounts show a shift of the perception of the class by the student. The student sees the classroom as an arena of interaction using technology to develop new meaning.

As the perception shifts, the role of the learner also shifts. Students begin to see that they can take control of their own learning. Investigation 3 has the students perform trials observing the robot's motion over different surfaces. At the start of class during the second day of Investigation 3, Student #1 directed her group members telling them, "Get the robot and let's go, I'll get the carpet." The students began to take more control and facilitated their journey through the module. There occurred a personal transformation in the learning process. It was also observed when Student #6 was heard telling her group, "Let's put a book under the carpet, see what happens." This attitude and behavior was evident in Investigation 4 as well when during the analysis of the data collected using the data logging feature of the robot, she asked the teacher, “Can we run the robot again?” At this moment, the role of the teacher has moved to facilitator and the role of the learner has moved from passive to active.

Subsequently, students became very critical of their work and debated during group discussions. In Investigations 5 and 6, during an interview Student #1 gave an account of the discussion as such, “So one, we were trying to decide how, like what kind of pattern would be better, like if we should do for the foot, if we should use like a spike, like more like spikes or if we should use the round to see which one would probably maybe grip the surface better, yeah…Like one person who had the spike idea and then the other person had the wave idea and others agreed as well.” This critical reflection on the design of spikes on the foot show evidence of higher order mental processes (Mezirow, 1990). From these discussions, students began to take control of their learning and meaning formation. As observed in a group discussion student #5 said, “We should measure the distance and time, calculate velocity and then observe how straight it traveled.” Student #6 summed the experience by saying “I’m not always a problem solver because sometimes, depending on what it is, it’s just not always worth the…trying to go out of my way to solve it. This activity has allowed me to determine if it needs to be solved, then I’ll solve it.”

Theme 5: Learning experiences underpinned by design thinking lead to positive student outcomes. At the core of the design thinking environment is the students’ progression through the engineering design cycle. Students at the beginning of the module enter the cycle at Step 1 Identifying the need or problem (Figure 19). The teacher presented the problem using the RFP. As they moved through the cycle, students in Step 2 began researching the problem.

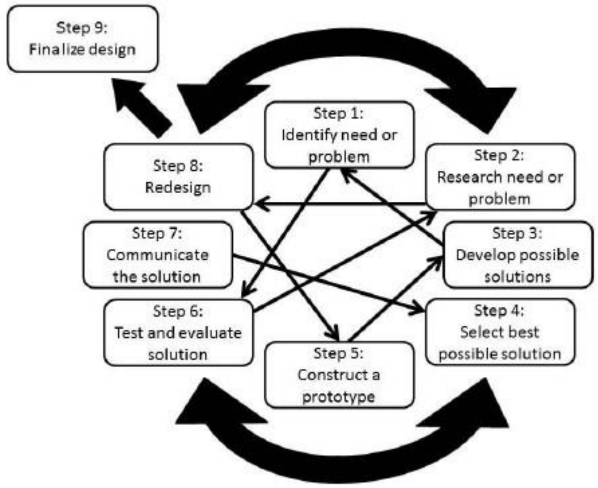


Figure 19. The Engineering Design Model. Adapted from "Infusing engineering design into high school STEM courses," by M. Hynes, M. Portsmore, E. Dare, C. Rogers and D. Hammer, 2011, National Center for Engineering and Technology Education website, p. 3. Copyright 2011 by the National Center for Engineering Technology.

The problem asked for a foot like device that would improve the motion of the robot in terms student derived meanings of performance and effectiveness. During the research phase of the engineering design cycle, the engineering groups are tasked to research information that will aid in their development of the solution prototype. To understand locomotion, the students were given three robots with different leg configuration. Each leg configuration made the robot move a certain way. In a whole class discussion, students came to a consensus to define effective movement. After the class agreed on what effective movement was, they performed experiments with the robot to gain an understanding of motion. During an experiment to determine the optimal leg configuration of the robot, Student #5 made an observation and entered it in their engineering notebook (Figure 20).

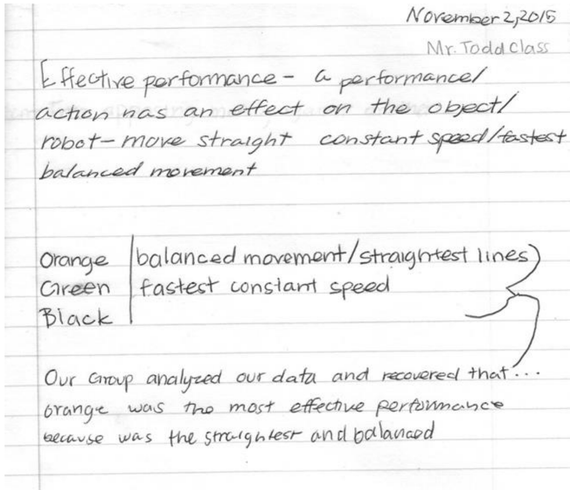


Figure 20. Student #5's Path Graph Observation Entry Engineering Notebook.

Student #4 made a similar entry in their engineering notebook describing the motion to determine optimal leg configuration in Figure 21. These observations that were made gave the students a unique perspective on the concepts of locomotion and gait. By doing their experimentation and research, each group is able to form a point of view that will address and assist the design of the solution. Kwek (2011) states that these activities promote a student centered learning environment and promotes activity guided problem solving that is connected to the real world context of the design challenge.

Figure 21. Student #4's Path Graph Observation Entry Engineering Notebook.

Students completed more experimentation to gather data that would aid them in their organization of ideas for solutions to the challenge. During Investigation 3, Student #7 made the remark to his group that "there is more friction on the carpet than on the floor." Testing the robot on three surfaces afforded the students the opportunity to make predictions about the robot's performance. Student #5 said to his group, "Bet that the robot is fastest on the floor." Students were then able to test their hypothesis and record their observations. In Investigation 4 students were able to further explore the concept of friction and look at it graphically. Student #2 during the analysis of the data generated from the data logging made the correlation of friction and "space" on the data logging graph Figure 22. Student #7 said, "So, if the spaces between one spike and another spike is bigger, than there must be something slowing the robot down."

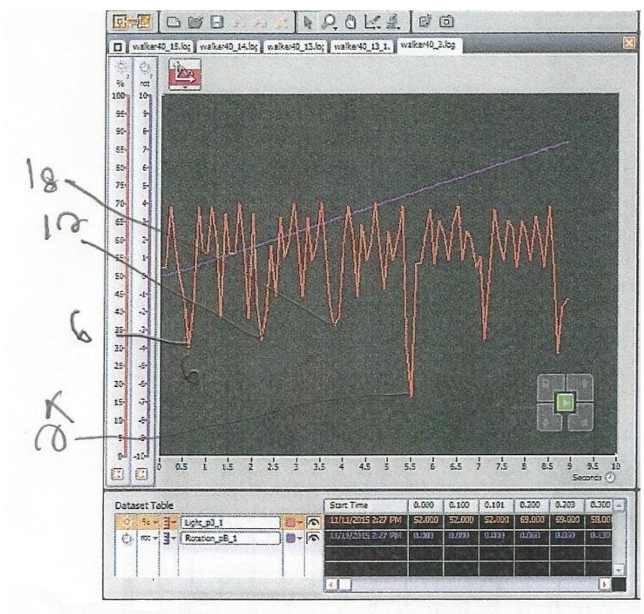


Figure 22. Student #7's Data Logging Graph Entry Engineering Notebook.

The data collected by the students informed their creation of solutions in Investigations 5 and 6. In Steps 3 and 4 of the Engineering Design Cycle, students create different solutions and choose the best two. Student #3 in an interview explained, "We changed it up because we were thinking about the friction so we had to get as close as possible to what we were thinking about the foot when it would experience friction with the surface. So we changed it enough." It is evident that the gathering of information to inform the design is guiding their decisions. Student #7's group decided that the foot should be able to operate on different surfaces. Student #7 suggested that "We should make the foot rigid so that it can be able to move on different surfaces (Figure 23)."

Figure 23. Student #7's Foot Design Draft and the Corresponding Printed Feet.

Student #1's group decided to edit their design during the computer drafting stage from their recorded design in their engineering notebook (Figure 24).

Figure 24. Student #1's Foot Design Draft and the Corresponding Printed Feet.

Investigation 6 allowed the students to take the data from the newly created feet along with data collected during the module and iterate their designs. Student #1 shares his group's willingness to iterate and make adjustments to his design. He says, "I won't say it was hard because you can just keep trying until you get something that works." Student #2 echoes his thoughts by saying, "It's like you put together this really good solution and if something doesn't turn around you've got to go back and fix it and that's okay but it's like it's just maybe intimidating because you've got to sit there and you're like okay, well the think I just did didn't work, now I have to sit here and think about something that I can do to fix whatever I just didn't do right." The ability and willingness to persevere is evident in these two statements.

Theme 6: Contextual relevance is enhanced when students have freedom to design their own learning journey. Contextual relevance refers to the connection the learner has with the situation. As depicted in the situated cognition concept map in Figure 2, the situated context is characterized as a relationship with a purpose. The students are a member of a community with a purpose or charge to respond to the RFP. The contextual relevance includes the shared tools, resources and processes used to respond to the RFP. When control is given to the students giving them the freedom to decide on the manner in which they want to respond, the connection between the context and student is enhanced. The students are not only bound by the same purpose but are motivated by meaningfulness toward creating the solution to the challenge.

During interviews, I asked students their perception and feeling about the integrative STEM module. Student #6 raves about the excitement of Step 5 building a prototype. Student #6 says, "I like 3-D printing because you get to see how stuff….Because it's not like regular printed like stuff that just come out like one dimension, you get to see like things really form, like a three-dimensional shape actually, coming, like printing out itself (Figure 25)." Student #4 made this remark about 3-D printing, "I liked it because I never saw something printed in 3-D before (Figure 26)." The student began to see himself as a manufacturer of a product. He was a maker. He then added, "It was different than what we do in math class, well math is like…it's like you follow this set of rules, this process and you have to get like this certain answer. But it helps when you can like do experiments and when you make mistakes you can see kind of how it would lead you to get this actual process and how you would actually get the answer that you're supposed to get."

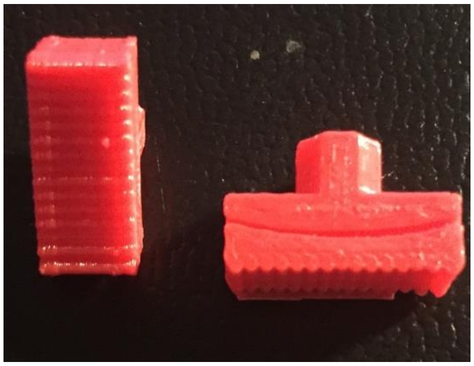


Figure 25. Student #6 Manufactured Foot Prototype

Figure 26. Student #4 Manufactured Foot Prototype

Student #1 replied that the context "made it feel more realistic and what you were doing would really help something, like an actual problem. Like you can kind of…if you take a real life example you can kind of bring it back to science and then you can kind of bring it back to math."

Students were guided through the process of taking control of their learning. Student #3 and his group designed the testing procedure that they felt would give them the best evidence for suggesting their foot design. Figure 27 is the group's created and designed procedure for testing their prototype foot-like devices. The entry shows how this group plans to collect data to support their prototype as the response to the RFP. The members of this group have decided to use their understanding of velocity as the main point of evidence to use their prototype.

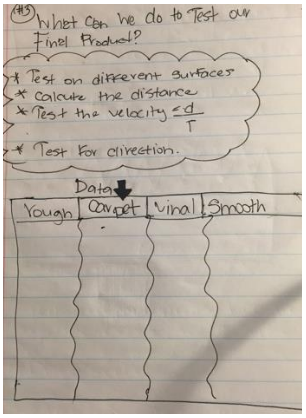


Figure 27. Student #3 Group Created Procedure for Testing Prototype

Student #6 was observed discussing the operation of the robot on an inclined plane. She suggested that they collect data of the robot operating on the table with one end supported by books (Figure 28). This manner of control goes further than the previous example due to the students' curiosity to perform experiments that were outside of the curriculum. Allowing the exploration of concepts using student driven inquiry takes the context and makes it meaningful to them. By the students taking control of what and how they learn they become invested owners of their learning.

When asked if they enjoyed the process, Student #2 said, "I did, I did like doing that part. I'm very artistic so I like I have this whole sketch book. It's actually in the classroom but it was fun, to put like…YOU create, like you draw it and I get to use my skills to kind of…It adds to the system that you're doing, it's like giving me an opportunity to be innovative (Figure 27)." Student #5 said "designing something and having it be created and then seeing how it works gives me a sense of accomplishment."

Summary of the Results

The quantitative results for achievement showed that there was a statistically significant difference in pretest and posttest scores. The analysis showed that students were able to correctly answer one to two questions more on the posttest than on the pre-test. The quantitative results for the paired samples *t*-test for each of the subscales of the Motivation and Engagement Scale survey showed that there were no significant differences in means for nine subscales: (1) self-belief, (2) valuing school, (3) learning focus, (4) planning, (5) task management, (6) persistence, (7) anxiety, (8) uncertain control and (9) disengagement. For the failure avoidance and self-sabotage subscales the results show a statistically significant difference. The analysis of the instrument showed that students after participating in activities of the REDC were not motivated by the fear of failure as they were at the beginning of REDC instruction. The fear of failure can overshadow any other motivation because they did not want to appear as a failure in the classroom. Failure avoidance may have motivated students to do work or many have motivated students to accept failure and not do the work at all. The analysis of the study showed that students' fear of failure lessened, they did not feel pessimistic or anxious when thinking about their school work. Students felt that the collaboration with group members and the environment created by the teacher, made the classroom room a safe place to explore experiment, innovate and create. The analysis showed that students did not feel the need to do things that would reduce their chance to achieve success. The self-sabotage feeling lessened and students felt that the curriculum allowed them to make the most of their abilities and afforded them the opportunity to take more control of their learning. Students showed a decreased bad feeling about school and became genuinely interested in the activities of the curriculum. The remaining subscales interpreted showed that students generally came to class moderately engaged. The subscales learning focus, persistence and self-belief according to the instrument scored a “B” out of an A to D scale. The usual activities that occurred in the class prior to the instruction of the REDC did not sustain the motivation and engagement. During the REDC integrative STEM instruction, motivation and engagement remained relatively constant, showing that their engagement was held by the robotics and engineering activities. The students’ fear of failing reduced as a result of engaging in the integrative STEM curriculum. Along with the decreased detrimental behavior that would prohibit success, students began to have a stronger feeling of control and purpose in their learning.

The qualitative analysis showed that the curriculum positively affected performance and engagement. Data triangulation from interviews, field notes, and student artifacts provided the story of the manner of engagement. Azevedo, diSessa and Sherin (2012) describe engagement in mathematics and science by the intensity and manner of participation in the learning activities. The students indicated that the humanistic perspective of the robot, their physical interaction and collaborative meaning making enhanced their engagement in the module. The social bond formed between student and the robot aided in the cognitive process developed by the students individually and collectively. The anthropomorphic relationship helps form the cognitive process by starting with an accessible knowledge structure as a base to help understand what the robot (non-human object) is doing (Epley, Waytz & Cacioppo, 2007). The students showed they had the ability to monitor and manipulate the robots to gain understanding of force, velocity, slope and other concepts. A hands-on real-world strategy has the capability to educate mathematics, science and engineering concepts (Carlson and Sullivan, 1999). The students were engaged in physical movement with the intent of gaining information to solve the engineering design challenge. Being in action also helped the students build community. Students were assigned to engineering groups that made up the engineering firm (entire class). Collaboration addresses the need for multiple perspective, different skill sets and different knowledge bases (Yuen et al., 2014). The study showed that students benefited from the collaborative nature of the curriculum. Students were able to explore and investigate ideas. When needed, students took the role of apprentice and were guided in their thinking during certain tasks during the curriculum. This evidence supports the findings from the quantitative analysis. The learning focus subscale remained constant throughout the instruction. Students were focused on the tasks and developing skills based on the knowledge structure they had or were made collectively in their learning community. The students displayed a constant learning focus by holding discussions, using graphic organizers and reflecting on the process used to obtain the final solution. Their fear of failure was seemingly reduced while working with their engineering group in the development of their solution. It was evident that collaboration provided a safe environment inhibiting behavior that would derail or limit their success.

The themes showed that an environment with transformative educational potential is important to the students' success. Christie, Carey, Robertson and Grainger (2015) argue that transformative learning is akin to developing independent thinkers. This study showed that students began this process by shifting from a passive to an active learner. During the shift, the students took control of their learning and became their own guide on this path. Furthermore, the learning environment was transformed as instruction shifted from being conducted in the traditional manner to occurring in two classes simultaneously while being taught by two teachers. The transformative nature of integrative instruction afforded unique learning experiences that were not constricted by subject or concept. The design thinking platform supported the students to engage in taking control of their learning. Design thinking allows for innovation, critical thinking, collaboration and creativity to solve problems (Carroll, 2014). Students were able to focus on the criteria of the project and were not concerned with getting a right answer. Moreover, students were able to explore mathematics concepts within the context of the situation ultimately lessening any fear or anxiety. Contextual relevancy incorporated hands-on experience, active and integrated learning and allowed students to design their own learning journey. The project-based learning component deepened students' understanding by letting their inquiry be the guide. Correlation of findings from qualitative and quantitative analyses was Affirmed that students became self-directed have ownership of their own learning. When students were challenged, they continued to work towards a solution for their response to the RFP. With a decreased apprehension and a subsided fear of failing, students felt comfortable traveling this path.

CHAPTER 5

Discussions

By using an exploratory single case study methodology utilizing both qualitative and quantitative research methods, this study investigated and described the effects of using project-based integrative STEM modules on eighth grade students' performance and engagement in a unit on functions in Algebra. The study was underpinned by the situated cognition framework. The study is guided by the following research questions:

1. What was the effect of using project-based, integrative STEM modules on 8^{th} grade student performance and engagement in learning a unit on linear functions?
2. What STEM-related situational factors contributed to 8th grade students' success in learning using project based, integrative STEM modules?

In concluding this research study, this chapter will situate the six findings within the context of relevant literature. Moreover, this chapter will provide an in-depth discussion of implications for practice and offer recommendations for future research.

Discussion of Research Findings

An investigation of the effect of using project-based, integrative STEM modules on eighth grade students' performance and engagement and the identification of STEM-situational factors that contribute to the students' success yielded six themes. Three themes emerged describing the effect of the integrative STEM module and three emerged identifying the STEM-situational factors:

1. The developing anthropomorphic relationship with the robot enhanced student engagement.
2. Purposeful and intentional student physical action supported meaningful engagement

in the design environment.

3. Purposeful collaboration promoted engagement through the construction of meaning and interaction.
4. A learning environment that has transformative learning potential fostered student success.
5. Learning experiences underpinned by design thinking led to positive student outcomes.
6. Contextual relevance was enhanced when students have freedom to design their own learning journey.

Connections to Literature

Recent national and local interest has placed a healthy interest in STEM. Bybee (2013) announced that two major national goals have been made: (1) increase proficiency of all students in STEM and (2) increase the number of students in STEM. Attending to the concerns of the first goal can result in a wide variety of studies looking to meet the metric stated in goal number one. Chapter 2 highlighted studies that were wide in range and scope with the intention of increasing student proficiency (Yuen, Boecking, Tiger, Gomez, Guillen, Arreguin & Stone, 2014; Barrett, Moran, & Woods, 2014; ChanJIn, Cartwright & Cole, 2015; Alfieri, Higashi, Shoop and Schunn, 2015; Star, Chen, Taylor, Durkin, Dede and Chao, 2014; Cuperman & Verner, 2008). In the wide variety of research reviewed in Chapter 2, there were similarities between the previous studies and certain aspects of the current study. A similarity between earlier studies and this study was the reported findings that inform strategies, products or processes to increase the interest and proficiency in STEM concepts and disciplines. ChanJin et al. (2015) claim that students who engage in robotics through extra-curricular competitions experience higher performance scores in mathematics and science. As well, Barrett, Moran and Woods (2014) argue that student participation in extracurricular meteorology and engineering camp increases student knowledge. Although these studies showed an increase in performance and engagement, the interventions studied occurred outside of the school day. The normal expectations of classroom instruction, management and student accountability were not present. The robotics competitions highlighted earlier were a part of an afterschool program. The meteorology and engineering competition was a summer program. Implementing these activities and experiences outside of the normal school day is very different than the integrative STEM model used in this study. The curriculum was instructed in the mathematics and science classes simultaneously and during the natural school day.

Another similarity between the studies previewed shows an increased in student performance, motivation and engagement. For example, Alfieri et al. (2015) contended that student self-efficacy and motivation improved due to the instruction of a specific mathematics topic using a gaming context. The computer based robot game had the students use their proportional reasoning skills to navigate an aquatic environment. However, the situated context of the studies reviewed did not relate to real world application. The studies appealed to the fantasy nature of gaming. In this study, the curriculum provided a contextual relevance that promotes the development of thinking skills that the students see as helpful in everyday life. Students were situated as engineers solving and engineering design challenges. Furthermore, the context dictated how the students used the tools and resources in resolving the challenge. As such, students became practitioners and engineers. The contextual background of the REDC curriculum differs from the context of the reviewed studies, which were situated in an entertainment gaming environment.

Cuperman and Verner (2008) reported findings that highlight the use of modeling with robotics created motivation to learn and understand STEM concepts. The similarity to the current study is the use of robotic models to engage and motivate student learning as they solve the engineering design challenge. This research study looks to investigate the use of robotic models in an integrated science and mathematics context over simultaneous instruction in a mathematics and science class taught by two teachers. Situated in a learning environment as described takes a deeper look at how modeling can be used in the classroom.

Examining the interaction between the robot and the student helps to describe the influence it has on engagement and student performance. Shahid, Khrahmer, and Swerts (2014) report that children who are able to form and develop a social bond with educational robots over time show positive learning effects. I argue that forming an anthropomorphic relationship aids in developing the social bond. This research study shows that students can be more expressive with robots than they are with their friends. Such relationship allows students the opportunity to construct arguments built upon an established base of understanding. The base of understanding results from a frame of reference that starts with their interaction with the environment around them. Lemaignan, Fink, Dillenbourg, and Braboszcz (2014) explain that anthropomorphizing the actions of the robot affords students the ability to explain things that are not well understood by them in terms of things they do understand. The learning was enhanced because of the bond created and the connection socially students had with the robot. In this relationship, social robots are seen as human-like mimicking many characteristics of living beings (Shahid et al., 2014). Several studies have shown that critical thinking skills can be developed along with other higher order thinking processes such as abstraction and analysis skills (Atmatzidou, 2016). Existing research on robotics in learning shows that children perceive robots as companions. Several questions still arise about the nature of the social bond that is seemingly formed and its influence on the child's academic performance. This current study has shown that an observable bond formed between students and the robot. The bio-inspired design of the robot gave students an opportunity to new perceptions regarding the nonliving object. Students attributed human characteristics to the robot and formed a bond with the model. I argue that the anthropomorphic relationship afforded a deeper understanding of the system that it represents and allowed a meaningful investigation into students' inquiry. Students employed the knowledge they have of themselves and extended it to the robot. Through iteration and testing of the prototype, students were able to form a deeper understanding of the system and use concepts of mathematics, science, and technology to engineer the solution for the project based learning challenge.

Another major finding of the current research study is that students were more engaged with hands on, physical activity when there was an explicitly stated reason to perform the activity. ChanJin et al. (2015) claim that students enjoy giving life to the robot and interacting with it. The art of learning by doing was what grabbed the attention of the students and engaged them in meaningful learning opportunities. Moye et al. (2014) defines "doing" as a hands on process that involves human needs and wants. "Doing" inspired innovation, creation and building. With this in mind, new approaches have been made to expand the "doing" experience using robots in the classroom from blindly doing tasks to purposefully experimentation with ideas. The emphasis was on the embodied nature of understanding where learning depends on the relationship between the mind, body, and the environment (Dautenhahn, 2007). Students in the current study actively engaged in authentic activities originally performed by engineers. During the design, test and iteration phase of the engineering design cycle, students performed tests that informed the redesign of the prototype to meet the criteria of the RFP. Dautenhahn

(2007) states that in this type of learning environment, robots move from being a computer on wheels to being an extension of the students' self. Students operating and observing the robot on different surfaces helped them form understanding through purposed motion that displayed the concept of force and velocity in action. The purpose was for students to gain knowledge through observation and data collection to inform their decision about their designs. Employing robots to simulate these instances provided a unique opportunity of embodiment where the "doing" is more authentic.

Likewise, there were findings of embodiment where the "doing" was more authentic. In the results it was noted that purposeful collaboration promotes engagement through collective meaning making and interaction. Peer-to-Peer relationships that have purpose and relevancy validate the learning experience. These collaborations make the social activities pertinent and not superficial. Freeman et al. (2008) explain that at the center of the social structure was the group's function to make sense of the situation around them. When the students understood their purpose collectively, meaningful discussions ensued in the effort of making sense of what challenges were before them. Collaboratively, the groups formed strategies and decided on the things they needed in order to solve the challenge. During the integrative STEM modules, students in their groups crafted a STEM specific language that was used to form meaning and create strategies needed to aid the problem solving process. Collaboration is key, as Freeman et al. (2008) assert, the community afforded confidence, motivation and persistence for learning where fear was lessened and opportunities for deep conceptual mastery prevailed. Findings of this research study reinforced the fact that group collaboration acted as the catalyst to foster learning the activities of the curriculum. The challenge given in the RFP motivated the group and the charge given by the RFP, promoted meaningful and purposeful collaboration in action and thought. Students in their engineering groups agreed on a common purpose and developed plans for designing and testing their solutions. Likewise, the collaboration provided a place where each of the members were supported and ideas could be shared safely. Members were relied upon for various expertise in the many skills used to solve the challenge. In this manner, the relationship between group members can be described as that of an expert and apprentice. Assistance such like this appeared to help members of the group as become academically and cognitively mature.

Additionally, results of this study showed that several STEM-situational factors contributed to the success of students. For example, the physical environment had transformative learning potentials, which directly influenced student success as they maneuvered new options and roles in the learning process (Elsey, 2011). I argue further that the transformative learning potential secured by the challenging situation motivated students to become self-disciplined and encouraged their self-control. The integrative STEM learning experience facilitated the integration of mathematics and science thereby providing a space for students to use their mathematics knowledge bases to interact with science, technology, and engineering design. Through collaborative work, students took part in constructing new knowledge and understanding supported by and situated in an integrated context. Schelly et al. (2015) explains that 3-D printing has a transformative educational potential by enabling students with the ability to innovate and create material objects through the design process. Immersing students in also in an environment where state-of-the-art instructional tools such as the 3-D design and printing allowed for the ingenuity and creativity to be a focal point of the activity. Students positioned themselves as contributors and makers. The shift in students' self-perception from a "line filler" to an idea creator fostered an atmosphere of success. The move continued as students began to explore questions they started to formulate during instruction. Schelly et al. (2015) argue that students can become critical of the world or the things around them. Through an interrelated sequence of action and reflection, students negotiated ways to make their problem solving better. Students were empowered to take control and responsibility for their learning. Hence, students changed their role from being passive receivers to active learners.

In this study I argue that learning environment afforded by integrative STEM activities underpinned by design thinking promoted student success. Kwek (2011) defines design thinking as an approach to learning that focuses on developing critical thinking and creativity through hands on projects that focus on empathy, encourage ideation and nurture problem solving skills. Students having the opportunity, engaged in practical work that test the theoretical concepts they were learning (Ayar, 2015). Students examined the problem critically. Each group engaged researched and used resources to create solutions that were tested and revised. Using this cycle of analysis, research, production, testing and revising created a setting where ideas flowed freely. I argue that engaging in this cycle peaked students' motivation and inspired interest to become innovators. The focus was not on arriving at the right answer but on the journey taken to achieve the solution. Mathematics and science concepts were used in concert with students' ideas and inquiries. Students had the ability to interact with new situations and were inspired to create and develop new meanings. Kwek (2011) contends that s increased interest, ability and self-confidence can positively impact learning.

Lastly, the contextual relevance contributed to success by allowing students to take ownership of their learning. Students were motivated to design and direct their learning paths. Skinner, Wellborn and Connell (1990) propose that students' perception of taking control of their learning can lead to success in school. Being immersed in an engineering design challenge, students conducted research independently with the purpose of designing a solution. Quinn (2015) contends that students should be placed in situations that encourage them to make decisions about their learning. By the same token, Harris, Penuel, D'Angelo, DeBarger, Gallagher, Kennedy, Cheng and Krajcik (2015) affirm that students' gaining control of their learning in a project-based learning environment leads to student success. During the project-based learning activity, students were encouraged to conduct independent research in order to gain conceptual and practical understanding of relevant mathematics concepts. Students were exposed to several experimentation techniques to understand balanced and unbalanced forces, motion and velocity. Moreover, students were given the ability and opportunity to analyze data collected from the robot in various ways to address questions that emerged during group deliberations and experiments. As students assumed the role of manufacturers, they became owners of the content, process and prototypes made in response to the RFP. Keengwe, Onchwari and Onchwari (2009) describe technology as having the ability to shift the role of the student where they are encouraged to construct meaning from their experiences. Students reflected on how they thought, learned and planned strategies used to solve problems. From the beginning of the curricular intervention, students were situated as problem solvers. They used the engineering design cycle as a guide to plan their course to toward a meaningful and relevant solution.

Some of the gaps in the literature identified areas where there was a lack of evidence reporting successful strategies, evidence of STEM curriculum promoting the use of high level mathematics skills and strategies for STEM curriculum integration. Findings reported in this study provided an overview of how the integrative STEM curriculum impacted student engagement and performance. For example, the anthropomorphic relationship between the student and the robot showed how engagement was fostered and promoted. The evidence of the relationship led to a need of understanding the complexity of the relationship and the effect it has on learning. Project-based learning curriculum that used engineering design challenges provided an integrated way for students to develop and use higher order critical thinking skills. The movement through the engineering design process promoted increased engagement in rigorous activities. For example, students explored slope of a line to calculate velocity then analyzed the velocity at different points of motion to detect the presence of friction. They were willing to complete the design challenge as their purpose changed. Instead of each student individually working on getting the same answer, students joined communities with a common purpose of creating solutions that met the criteria of the challenge.

The STEM integrated curricular intervention in the mathematics and science classroom simultaneously displayed a design example for discipline integration. The use of this model added to the discussion of strategies used to implement integrative STEM across the science and mathematics curricula.

Implications for Practice

The aim for this research study was to explore the effect on performance and engagement when using a project-based, integrative STEM module on eighth grade students' performance and engagement in learning a unit on functions and identify the STEM-situational factors that contribute to their success. The exploratory nature of the case study intends to identify areas of further study which call for deeper investigation. The implications for practice include continual study and examination on the design and structure of the STEM learning space and simultaneous integration of disciplines throughout teaching and learning.

The STEM learning space is ever changing, just like the learner that will occupy these rooms. Estes et al. (2014) describe several significant characteristics that should be found in today's STEM classroom. Today's classroom must honor the fact that students today learn and communicate differently from previous generations. Integrated technology should be present that encourages for small group work and individual learning. The classroom allows for intentional learning where the students become advocates for their own schooling. It should nurture relationships where community, collaboration and learning are encouraged. The place should also be a crossroads for community, business and academic partnership. There is limited literature outlining the design of such spaces. This research aims to be a catalyst for discussions regarding this matter.

The model of integration, in this study, implements one description called integrative STEM. Wells (2014) defines it as the design based approach using technology and engineering to teach science and mathematics content. This research study has investigated the implementation of this model in the science and mathematics class simultaneously. The definition of STEM in schools nationwide has been a matter of preference and preparation. With the evidence of the model communicated in this study, schools, communities and academia should be motivated to rethink what STEM integration looks like. This study aims to be a catalyst for the study and design of several models of integration.

Recommendations for Future Research

The state of STEM education research has not changed much since Brown (2012) claimed that there were many attempts to answer the goal of STEM education: (1) increase student proficiency and (2) increase the students in the STEM major and career pipeline. The reviewed studies (Yuen, Boecking, Tiger, Gomez, Guillen, Arreguin & Stone, 2014; Barrett, Moran, & Woods, 2014; ChanJIn, Cartwright & Cole, 2015; Alfieri, Higashi, Shoop and Schunn, 2015; Star, Chen, Taylor, Durkin, Dede and Chao, 2014; Cuperman & Verner, 2008) showed the wide variety of research conducted. Several areas would benefit from focused research including the social anthropomorphic bond between the student and robot, teacher professional development, models of STEM integration, and writing in STEM. An investigation into these areas will provide a clearing agent to the current muddied waters of STEM.

The social bond between student and robot. Findings of this study highlighted the bond between the student and the robot as anthropomorphic. To further this discussions, aspects of the student-robot interaction should look into the cognitive processes developed as a result of the bond. Furthermore, an investigation of the influences on the social bond, such as cultural background, age or gender, and the impact it has on learning is necessary.

Teacher Professional Development. In the spirit of the old saying, "you can't teach an old dog new tricks," school districts are faced with the dilemma of helping teachers change their practices. At the same time, colleges and universities are challenged to train new teachers with these competencies. With time constraints, district pressures and an ever changing student, it has become difficult to train teachers "on the fly" to become STEM teachers. One area of major concern is providing professional development in the appropriate use of relevant and cutting edge technology in the classroom. Oftentimes teachers are well versed in more traditional ways of teaching with little working knowledge of coding, robotics systems, 3-D printers and laser cutters. This area of teacher professional development is rich in opportunity.

Models of STEM Integration. This area is still in need of research to provide blueprints to create a learning environment that integrates two or more disciplines at the same time. This study investigated how using an example model was implemented in a mathematics and science class simultaneously. By providing insight to the professional development needed for this model, planning and implementation may inform practitioners on the design of integrative STEM in schools.

Incorporating Writing in STEM. Writing is very important to the design process. Students have a desire to only engage in hands on activities as seen by the current study. Research in strategies to encourage writing in all STEM disciplines would be very helpful and beneficial.

Conclusion

Findings reported in this study support the fact assertion that using robotics maintained curiosity and interest when presented in the mathematics and science classrooms. The effect on engagement was evident by the three themes: (1) the developing anthropomorphic relationship with the robot enhanced student engagement, (2) engagement is impacted by purposeful and intentional student physical action, (3) purposeful collaboration promotes engagement through the construction of meaning and interaction. The STEM-situational factors that contribute to student success emerged from three themes: (1) a learning environment that has transformative learning potential fosters student success, (2) learning experiences underpinned by design thinking lead to positive student outcomes, (3) contextual relevance is enhanced when students have freedom to design their own learning journey.

As a nation we are in an exciting yet frightening period. Bybee (2013) describes this as our "Sputnik moment." Will we answer the call and let this time motivate and inspire up to greater heights or do we shrink and cower under the pressures affecting us during this period? It has been my intention since the day I walked into the classroom, to do whatever it takes to prepare students for the rest of their lives. The situations that they will encounter will require critical thinking skills, adaptation, and innovation. With the findings of this study, we can begin the journey to insure that each student is prepared for success in our ever advancing technological world.

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Appendix A: Biomechanics Standard and Activity Matrix

Technological Systems 21.023 Integrated STEM Course Matrix -- Bio-Mechanics: Locomotion

Investigation 2		**Essential Question**	What is locomotion? How do systems interact to allow locomotion?	
	CTAE	**GPS Standard**	MSENGR-TS-1: The students will develop an understanding of the Universal Systems Model.	
	Science Correlations	**Practices**	2. Developing and using models	4. Analyzing and interpreting data
			3. Planning and carrying out investigations	5. Using mathematics and computational thinking
		Crosscutting Concepts	1. Patterns	4. Systems and system models
			2. Cause and effect: Mechanism and explanation	6. Structure and function
			3. Scale, proportion, and quantity	
		Core Ideas	PS2.A: Forces and Motion	ETS1.A.: Defining and Delimiting and Engineering Problem.
		GPS Characteristics of Science	S8CS3. Students will have the computation and estimation skills necessary for analyzing data and following scientific explanations	S8CS5. Students will use the ideas of system, model, change, and scale in exploring scientific and technological matters.
			S8CS4. Students will use tools and instruments for observing, measuring, and manipulating equipment and materials in scientific activities utilizing safe laboratory procedures.	S8CS6. Students will communicate scientific ideas and activities clearly.
		GPS Content Standards	S8P3. Students will investigate the relationship between force, mass, and the motion of objects.	a. Determine the relationship between velocity and acceleration.
				c. Demonstrate the effect of simple machines on work.
	Math Correlations	**CCGPS**	MCC8.F.1 Understand that a function is a rule that assigns to each input exactly one output. The graph of a function is the set of ordered pairs consisting of an input and the corresponding output.	
			MCC8.F.2 Compare properties of two functions each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions).	
		Standards of Mathematical Practices	2 Reason abstractly and quantitatively.	
			3 Construct viable arguments and critique the reasoning of others.	

Appendix A: Biomechanics Standard and Activity Matrix cont.

			Movement and Gait Activities	Outcomes/Products
Investigation 2	2x	0.1	Present RFP: Redesign an existing mechanism (robot) for stability and efficiency traverse varied terrains. Discuss various locomotion strategies using legs. Develop a list with multiple examples of strategies.	Journal entry-strategy list.
		0.2	Exploring locomotion with models. Introduce the 3 different NXT Insectobots. Have the groups examine each and record any differences. Assign one bot for testing. Explore the bot with the tether.	Journal entry-difference table.
		0.3	Groups use each of the robots and run trials. Graph each trial on the roll graph paper using the marker attachment. Timekeeper for each group should time stamp graphs. Each bot is represented by a different color all on same graph.	Graph data with time stamp.
		0.4	Use graph data to calculate average velocity for the five trials of each design. Prepare a brief presentation for the class on the relative performance of each bot. Record averages in journal.	Journal entry-averages.
		0.5	Groups present findings and graphs. Class discussion comparing the performance. Is there a clear winner?	Presentations.
		0.6	Show CRAB Lab video. Discuss the term gait. Was one robot exhibiting an ideal gait based on the video. What might explain any variations? Correct all robots so that they all have legs in the ideal configuration.	Discussion.

Engineering & Technology Standard	Science Correlations						Math Correlations			iste-nets				English Language Arts Correlations		
	Practices		Crosscutting Concepts		Core Ideas		Common Core	Practices		Student		Teacher		Reading	Writing	Speaking & Listening
MSENGR-TS-1	1	5	1	5	PS2.A	ETS1.A	MCC8.F.1	1	5	1	5	1	5	RST.8.3	WHST.8.1	SL.8.1
	2	6	2	6			MCC8.F.2	2	6	2	6	2		RST.8.4	WHST.8.2	SL.8.4
	3	7	3	7				3	7	3		3		RST.8.7	WHST.8.10	
	4	8	4	8				4	8	4		4				

Characteristics of Science			GPS Content Standards	
1	5	9	S8P3.a	
2	6	10	S8P3.c	
3	7			
4	8			

Appendix A: Biomechanics Standard and Activity Matrix cont.

Technological Systems 21.023 Integrated STEM Course Matrix -- Bio-Mechanics: Locomotion

Investigation 3		**Essential Question**	How do forces interact within the system? Where is the energy flow?	
	CTAE	**GPS Standard**	MSENGR-TS-3: The students will develop an understanding of how humans interact with systems.	
	Science Correlations	**Practices**	1. Defining problems (for engineering)	
			2. Developing and using models	
			3. Planning and carrying out investigations	
			6. Designing solutions.	
		Crosscutting Concepts	1. Patterns	5. Energy and matter: Flows, cycles, and conservation
			2. Developing and using models	6. Structure and function
			4. Systems and system models	7. Stability and change
		Core Ideas	PS2.A.: Forces and Motion	PS3.A.: Definitions of Energy
			PS2.B.: Types of Interactions	PS3.C.: Relationship Between Energy and Forces.
			ETS1.A.: Defining and Delimiting and Engineering Problem.	ETS1.B.: Developing Possible Solutions.
		GPS Characteristics of Science	S8CS3. Students will have the computation and estimation skills necessary for analyzing data and following scientific explanations	S8CS7. Students will question scientific claims and arguments effectively.
			S8CS5. Students will use the ideas of system, model, change, and scale in exploring scientific and technological matters.	S8CS10. Students will enhance reading in all curriculum areas by: c.Building vocabulary knowledge.
		GPS Content Standards	S8P3. Students will investigate the relationship between force, mass, and the motion of objects.	a. Determine the relationship between velocity and acceleration.
				b. Demonstrate the effect of balanced and unbalanced forces on an object in terms of gravity, inertia, and friction.
	Math Correlations	**CCGPS**	MCC8.F.2 Compare properties of two functions each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions)	
		Standards of Mathematical Practices	3. Construct viable arguments and critique the reasoning of others.	

			Motion and Surfaces Activities	**Outcomes/Products**
Investigation 3		0.1	Foot-based locomotion; what is occuring? Students summarize experience with the three insectbots. How are these bots propelled forward? What is the motion of the legs called? Draw a diagram of the ideal gait.	Journal entry. Solid explanations. Clear illustrations.
		0.2	Traction. Students explore the amount of grip generated between their foot and three distinct surfaces.	Data table recording interactions with surfaces.
		0.3	Initial exploration of force vectors and diagrams. Basics. What is happening with your foot? Using data from previous activity to draw diagrams. How do these diagrams represent slippage?	Correctly drawn diagrams.
	2x	0.4	Run the insectbot across each of the three surfaces. Measure elapsed time to traverse 3 feet (5 trials at 80% power.) Prepare a briefing for the class.	Data table.
		0.5	Class discussion following group briefings. Did the performance vary to any great degree? Why might this be the case? Sketch force diagrams for each surface.	Three force diagrams.
		0.6	Discuss diagrams using student examples. Is energy being transferred or lost at the interface between foot and surface? How might this be measured?	Journal summary.

Engineering & Technology Standard	**Science Correlations**						**Math Correlations**			**iste-nets**				**English Language Arts Correlations**		
	Practices		**Crosscutting Concepts**		**Core Ideas**		**Common Core**	**Practices**		**Student**		**Teacher**		**Reading**	**Writing**	**Speaking & Listening**
MSENGR-TS-3	1	5	1	5	PS2.A	ETS1.A	MCC8.EE.7	1	5	1	5	1	5	RST.8.3	WHST.8.1	SL.8.1
	2	6	2	6	PS2.B	ETS1.B	MCC8.F.2	2	6	2	6	2		RST.8.7	WHST.8.2	SL.8.4
	3	7	3	7	PS3.A			3	7	3		3			WHST.8.4	
	4	8	4	8	PS3.C			4	8	4		4			WHST.8.10	

Characteristics of Science			**GPS Content Standards**	
1	5	9	S8P3.a	
2	6	10	S8P3.b	
3	7			
4	8			

Appendix A: Biomechanics Standard and Activity Matrix cont.

Technological Systems 21.023 Integrated STEM Course Matrix -- Bio-Mechanics: Locomotion

Investigation 4		**Essential Question**	Can system interactions be explained using biological analogs?	
	CTAE	**GPS Standard**	MSENGR-TS-4: The students will develop an understanding of how systems evolve from one stage to another.	
	Science Correlations	**Practices**	2. Developing and using models	8. Obtaining, evaluating, and communicating information
			3. Planning and carrying out investigations	
		Crosscutting Concepts	1. Patterns	5. Energy and matter: Flows, cycles, and conservation
			2. Developing and using models	6. Structure and function
		Core Ideas	PS2.A.: Forces and Motion	PS2.B.: Types of Interactions
			PS2.C.: Stability and Instability in Physical Systems.	
		GPS Characteristics of Science	S8CS5. Students will use the ideas of system, model, change, and scale in exploring scientific and technological matters.	S8CS8. Students will be familiar with the characteristics of scientific knowledge and how it is achieved.
			S8CS6. Students will communicate scientific ideas and activities clearly.	S8CS9. Students will understand the features of the process of scientific inquiry.
		GPS Content Standards	S8P3. Students will investigate the relationship between force, mass, and the motion of objects.	b. Demonstrate the effect of balanced and unbalanced forces on an object in terms of gravity, inertia, and friction.
	Math Correlations	**CCGPS**	MCC8.EE.7 Solve linear equations in one variable.	
			MCC8.F.2 Compare properties of two functions each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions)	
		Standards of Mathematical Practices	3. Construct viable arguments and critique the reasoning of others.	

			Data Logging Activities	**Outcomes/Products**
Investigation 4		0.1	Introduce NXT Data Logging. Using same robots (wheels installed as outlined.) Demonstrate basics of data acquisition both live and remote. MEMORY MANAGEMENT! Discuss demo graphs including slope relevance.	Notes in journal. Annotated handout.
		0.2	Remind students about memory! Remote data collection. Try several runs using wheeled bots. Once confident, reinstall legs in proper configuration. Introduce the second power level (50%.) Discuss potential diffences between 50 and 80%.	Record predictions in journal.
	2x	0.3	Run multiple trials (5 successful) with each power level. Save a screen shot (demonstrate how to do this) of each graph for later analysis. Select the graph that best represents the average performance for each power level.	Graph analysis worksheet.
		0.4	Calculate the slope for each power level using the selected graphs. Calculate the average velocity for each power level from the same graphs. Does the slope result match the calculated average? What might be happening?	Calculations in journal.
		0.5	Is there evidence of slippage? If so, what conditions might be responsible? Sketch a force diagram for a foot for each power level.	Force diagrams.
		0.6	Class discussion of results. Relate to previous activities. Does data-logging make it easier to see trends?	Discussion.

Engineering & Technology Standard	**Science Correlations**						**Math Correlations**			**iste-nets**				**English Language Arts Correlations**		
	Practices		**Crosscutting Concepts**		**Core Ideas**		**Common Core**	**Practices**		**Student**		**Teacher**		**Reading**	**Writing**	**Speaking & Listening**
MSENGR-TS-4	1	5	1	5	PS2.A		MCC8.EE.7	1	5	1	5	1	5	RST.8.3	WHST.8.1	SL.8.1
	2	6	2	6	PS2.B		MCC8.F.2	2	6	2	6	2		RST.8.7	WHST.8.10	SL.8.4
	3	7	3	7	PS2.C			3	7	3		3				
	4	8	4	8				4	8	4		4				

Characteristics of Science			**GPS Content Standards**	
1	5	9	S8P3.b.	
2	6	10		
3	7			
4	8			

Appendix A: Biomechanics Standard and Activity Matrix cont.

Technological Systems 21.023 Integrated STEM Course Matrix -- Bio-Mechanics: Locomotion

Investigation 5		Essential Question	How is a complex system affected by the modification of a single variable within one subsystem?	
	CTAE	GPS Standard	MSENGR-TS-5: The students will recognize and be able to forecast trends in the development of technological systems.	
	Science Correlations	Practices	1. Defining problems (for engineering)	4. Analyzing and interpreting data
			2. Developing and using models	6. Designing solutions.
			3. Planning and carrying out investigations	
		Crosscutting Concepts	2. Developing and using models	5. Energy and matter: Flows, cycles, and conservation
			4. Systems and system models	7. Stability and change
		Core Ideas	PS2.A.: Forces and Motion	PS3.C.: Relationship Between Energy and Forces.
			PS2.C.: Stability and Instability in Physical Systems.	ETS1.A.: Defining and Delimiting and Engineering Problem.
			PS2.B.: Types of Interactions	ETS1.B.: Developing Possible Solutions.
			PS3.A.: Definitions of Energy	ETS1.C.: Optimizing the Design Solution
		GPS Characteristics of Science	S8CS4. Students will use tools and instruments for observing, measuring, and manipulating equipment and materials in scientific activities utilizing safe laboratory procedures.	S8CS5. Students will use the ideas of system, model, change, and scale in exploring scientific and technological matters.
				S8CS9. Students will understand the features of the process of scientific inquiry.
		GPS Content Standards	S8P2. Students will be familiar with the forms and transformations of energy.	b. Explain the relationship between potential and kinetic energy.
			S8P3. Students will investigate the relationship between force, mass, and the motion of objects.	b. Demonstrate the effect of balanced and unbalanced forces on an object in terms of gravity, inertia, and friction.
	Math Correlations	CCGPS	MCC8.F.5 Describe qualitatively the functional relationship between two quantities by analyzing a graph(e.g., where the function is increasing or decreasing, linear or nonlinear). Sketch a graph that exhibits the qualitative features of a function that has been described verbally.	
			MCC8.SP.1 Construct and interpret scatter plots for varying measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.	
		Standards of Mathematical Practices	1. Make sense of problems and persevere in solving them.	5. Use appropriate tools strategically.
			2. Reason abstractly and quantitatively.	7. Look for and make use of structure.

			Activities	Outcomes/Products
Investigation 5		0.1	Reintroduce the RFP. Class discussion about surfaces and feet. What might an optimum foot look like? Introduce a new surface (FRP pebble sheet.) Outline team requirements for response to the RFP.	Team organization chart.
		0.2	Introduction to SolidWorks. Use large scale models to demonstrate simple modeling processes such as an extruded cut and an extrusion. Guided student practice on sample part. Student demos on projector. Develop several potential foot design sketches.	Sketches in journal.
		0.3	Throughout testing record 5 trials per change. All trials logged with the NXT software. Design changes should consider: physical constraints, force interaction, energy transfer due to friction, optimal stability of the robot, and transfer of energy.	Develop a data collection format for the journal.

Engineering & Technology Standards	Science Correlations						Math Correlations			iste-nets				English Language Arts Correlations		
	Practices		Crosscutting Concepts		Core Ideas		Common Core	Practices		Student		Teacher		Reading	Writing	Speaking & Listening
MSENGR-TS-5	1	5	1	5	PS2.A	PS3.C	MCC8.F.5	1	5	1	5	1	5	RST.8.3	WHST.8.1	SL.8.1
MSENGR-TS-6	2	6	2	6	PS2.B	ETS1.A	MCC8.SP.1	2	6	2	6	2	6	RST.8.4	WHST.8.2	SL.8.4
	3	7	3	7	PS2.C	ETS1.B		3	7	3	7	3	7	RST.8.7	WHST.8.4	
	4	8	4	8	PS3.A	ETS1.C		4	8	4	8	4	8		WHST.8.10	

Characteristics of Science			GPS Content Standards	
1	5	9	S8P2.b.	
2	6	10	S8P3.b.	
3	7			
4	8			

Appendix A: Biomechanics Standard and Activity Matrix cont.

Technological Systems 21.023 Integrated STEM Course Matrix -- Bio-Mechanics: Locomotion

Investigation 6		Essential Question	How has your system evolved through iteration? How can technology facilitate the design process?	
	CTAE	GPS Standard	MSENGR-TS-7: Students will develop leadership skills and work ethics.	
	Science Correlations	Practices	1. Defining problems (for engineering)	5. Using mathematics and computational thinking
			2. Developing and using models	6. Designing solutions.
			3. Planning and carrying out investigations	7. Engaging in argument from evidence
			4. Analyzing and interpreting data	8. Obtaining, evaluating, and communicating information
		Crosscutting Concepts	2. Developing and using models	6. Structure and function
			4. Systems and system models	7. Stability and change
			5. Energy and matter: Flows, cycles, and conservation	
		Core Ideas	PS2.A.: Forces and Motion	PS3.C.: Relationship Between Energy and Forces.
			PS2.B.: Types of Interactions	ETS1.A.: Defining and Delimiting and Engineering Problem.
			PS2.C.: Stability and Instability in Physical Systems.	ETS1.B.: Developing Possible Solutions.
			PS3.B.: Conservation of Energy and Energy Transfer	ETS1.C.: Optimizing the Design Solution
		GPS Characteristics of Science	S8CS5	S8CS7
			S8CS6	S8CS9
		GPS Content Standards	S8P2. Students will be familiar with the forms and transformations of energy.	b. Explain the relationship between potential and kinetic energy.
			S8P3. Students will investigate the relationship between force, mass, and the motion of objects.	Sub strands a, b, and c.
	Math Correlations	CCGPS	MCC8.SP.1 Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.	
		Standards of Mathematical Practices	1 Make sense of problems and persevere in solving them.	6. Designing solutions.
			2. Reason abstractly and quantitatively. 4. Analyzing and interpreting data	8 Look for and express regularity in repeated reasoning.

			Activities	Outcomes/Products
Investigation 6		0.1 - 0.8	Select roles within each design team. Second part iteration due day 4, investigation 6. Review criteria and constraints. Throughout testing recall 5 trials per change. Design changes should consider: physical constraints, force interaction, energy transfer due to friction, optimal stability of the robot, and transfer of energy. Preparation of a design brief. Third part iteration due day 1, investigation 7.	SolidWorks designs supported by thinking in journal entries. Data properly recorded and analysis done. Rational explanations explain design changes. Design brief draft. First and second foot designs.

Engineering & Technology Standard	Science Correlations: Practices		Science Correlations: Crosscutting Concepts		Science Correlations: Core Ideas	
MSENGR-TS-7	1	5	1	5	PS2.A	PS3.C
	2	6	2	6	PS2.B	ETS1.A
	3	7	3	7	PS2.C	ETS1.B
	4	8	4	8	PS3.B	ETS1.C

Math Correlations: Common Core	Math Correlations: Practices		iste-nets: Student		iste-nets: Teacher	
MCC8.SP.1	1	5	1	5	1	5
	2	6	2	6	2	
	3	7	3		3	
	4	8	4		4	

English Language Arts Correlations: Reading	Writing	Speaking & Listening
RST.8.4	WHST.8.1	SL.8.1
RST.8.7	WHST.8.2	SL.8.4
RST.8.8	WHST.8.4	

Characteristics of Science			GPS Content Standards	
1	5	9	S8P2.b.	
2	6	10	S8P3.a.	
3	7		S8P3.b.	
4	8		S8P3.c.	

Appendix A: Biomechanics Standard and Activity Matrix cont.

Technological Systems 21.023 Integrated STEM Course Matrix -- Bio-Mechanics: Locomotion

Investigation 7		Essential Question	What are the challenges involved in manufacturing a new component of a system?	
	CTAE	GPS Standard	MSENGR-TS-6: The students will recognize relationships among technologies and assess the impact of technological systems.	
	Science Correlations	Practices	2. Developing and using models	8. Obtaining, evaluating, and communicating information
			4. Analyzing and interpreting data	
		Crosscutting Concepts	5. Energy and matter: Flows, cycles, and conservation	7. Stability and change
			6. Structure and function	
		Core Ideas	PS2.A.: Forces and Motion	PS3.C.: Relationship Between Energy and Forces.
			PS2.B.: Types of Interactions	ETS1.B.: Developing Possible Solutions.
			PS2.C.: Stability and Instability in Physical Systems.	ETS1.C.: Optimizing the Design Solution
			PS3.B.: Conservation of Energy and Energy Transfer	
		GPS Characteristics of Science	S8CS5	S8CS8
			S8CS6	S8CS9
		GPS Content Standards	S8P2. Students will be familiar with the forms and transformations of energy.	b. Explain the relationship between potential and kinetic energy.
			S8P3. Students will investigate the relationship between force, mass, and the motion of objects.	Sub strands b and c.
	Math Correlations	CCGPS	MCC8.SP.1 Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.	
		Standards of Mathematical Practices	1. Make sense of problems and persevere in solving them.	8. Look for and express regularity in repeated reasoning.

			Final Presentation Activities	Outcomes/Products
Investigation 7		0.1	Formulate a formal Letter of Response. Final Acceptance Tests: Initial pitch (3 minutes) feedback	Journal and design brief. Final robot.
	2x	0.3	Final Acceptance Tests: Final pitch (3 minutes)	Final robot.

Engineering & Technology Standard	Science Correlations						Math Correlations			iste-nets				English Language Arts Correlations		
	Practices		Crosscutting Concepts		Core Ideas		Common Core	Practices		Student		Teacher		Reading	Writing	Speaking & Listening
MSENGR-TS-6	1	5	1	5	PS2.A	PS3.C	MCC8.SP.1	1	5	1	5	1	5	RST.8.7	WHST.8.2	SL.8.1
	2	6	2	6	PS2.B	ETS1.B		2	6	2	6	2		RST.8.8	WHST.8.4	SL.8.4
	3	7	3	7	PS2.C	ETS1.C		3	7	3		3				
	4	8	4	8	PS3.B			4	8	4		4				

Characteristics of Science			GPS Content Standards	
1	5	9	S8P2.b.	
2	6	10	S8P3.b.	
3	7		S8P3.c.	
4	8			

Appendix B: Interview protocol (Sample)

Introduction

My name is Storm Robinson. I am a PhD student at Georgia State University. Thank you so much for your help. Today you are going to take part in a study on integrative STEM teaching and learning. This study will help with the development of teacher and student materials to make learning engaging and meaningful. So your help is very important and I thank you.

We want to understand what you are thinking and how you feel during the instruction of integrative STEM curriculum. Would you like to participate in this interview?

Yes: continue

No: stop the interview

I am going to ask you some questions. Before I start, I would like to let you know that I am going to record what we say using this digital recorder. I will not use your name to identify the audio recording. The recording will be stored on a password protected hard drive. Are there any questions?

1. What project are you doing in mathematics class?
    - Do you think the project is important? Why or why not?
2. Have you learned anything about mathematics? Why or why not?
3. Have you learned anything about science? Why or why not?
4. Have you learned anything about engineering? Why or why not?
5. How often do you have projects like this in class?

Appendix B: Interview protocol (Sample) cont.

6. How is this class the same or different from other classes?

- Do you do this type of projects in any other classes?

7. I am going to describe different teaching strategies that your teacher used in the class. I want you to describe something that you like or something that you didn't like about the strategy? One of the things the teacher did was at the beginning of the lesson he presented a problem. Was it helpful or not?

- The teacher guided you though the calculation of velocity with data collected from your robot.
- You were allowed to discuss with your group how graphs can determine slope and velocity
- You used the robot to gain understanding of force.

8. Tell me how you feel about the robots, computer aided design and 3-D printing?

- Did they help or hurt the lesson?
- Could you have solved the problem using something else?
- Do you feel like you are using up to date technology?

9. What was the best/worst part of the activities?

10. Let's imagine that you receive another RFP to design a device that helps people with mobility issues due to diabetes. How would you solve this challenge?

11. Since there was little homework from the activities, did you think about them after school or have a discussion with a family member or friend about what you did in class?

12. Did these activities help your problem solving? Why or why not?

Appendix B: Interview protocol (Sample) cont.

13. Would you agree that these activities increase your interest in science, technology, engineering or mathematics? Why or why not?

14. What do you think mathematicians do in their normal workday? Scientists? Engineers?

15. Did you enjoy the experience overall?

Appendix C: Observation protocol (Sample)

Transforming STEM Learning
and
Evaluation of the North Carolina Race to the Top STEM Initiative

Classroom Observation Protocol

RTI International
SERVE Center at UNC-Greensboro
Friday Institute at North Carolina State University

Suggested citation:
Arshavsky, N., Edmunds, J., Charles, K., Rice, O., Argueta, R., Faber, M., Parker, B. (2012). STEM Classroom Observation Protocol. Greensboro, NC: The SERVE Center, University of North Carolina at Greensboro. Available at http://www.serve.org/STEM.aspx

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Appendix C: Observation protocol (Sample) cont.

Study of STEM Learning

Classroom Observation Protocol: Academic Year 2012–2013

Observer/Interviewer:_________________ School Name:______________

Observation date: ____________ Time Start: ________ End: ______

Teacher Ethnicity: _____ Teacher Gender: Male___Female__

Grade Levels of students: _______ Course Title:_____________________

Students: Number of Males _____ Number of Females _____

Classroom Race/Ethnicity: % Minorities (approximate) ___________

Please give a brief description of the class observed, including:

- the classroom setting in which the lesson took place (space, seating arrangements, environment and personalization, *etc*.),
- when in the overall lesson sequence this class takes place (toward the beginning of a unit, in the middle of a unit, toward the end)
- any unusual context of the lesson (interruptions, etc.)

Use diagrams if they seem appropriate.

Lesson Topic:

Lesson Goals as presented *by the teacher to the students*:

Curriculum Materials Used: (include any textbook, lab materials, or resources used)

Lesson Structure: Briefly describe the structure of the lesson (e.g. 5 min quiz, followed by 25 min of homework review, followed by 10 min of whole class discussion, followed by 15 min individual work on worksheets; note whether there was a conceptual summary at the end of the lesson; if summative assessment is present, please describe).

As implemented, the lesson mostly focused on (most time was spent on):

Appendix C: Observation protocol (Sample) cont.

- ☐ Most time spent on practicing algorithms/basic skills and procedures/vocabulary
- ☐ About equal time spent on practicing algorithms/basic skills and procedures/vocabulary and on concept development and meaningful learning
- ☐ Most time spent on inquiry/meaningful learning and genuine problem solving

1. Mathematics and Science Content

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation. DK = Observer does not know or is not able to make this determination.

1a. Math and science content information was accurate.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1b. Teacher's presentation or clarification of mathematics or science content knowledge was clear.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1c. Teacher used accurate and appropriate mathematics or science vocabulary.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1d. Teacher/students emphasized meaningful relationships among different facts, skills, and concepts.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1e. Student mistakes or misconceptions were clearly addressed (emphasis on correct content here).	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1f. Teacher and students discussed key mathematical or science ideas and concepts in depth.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1g. Teacher connected information to previous knowledge.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1h. Appropriate connections were made to other areas of mathematics/science or to other disciplines.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1i. Appropriate connections were made to real-world contexts.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
Summary: Quality of Mathematics and Science Content	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Record specific examples below.

Appendix D: Engagement Survey Sample Items

Name of measure	Subscales	Sample items
Motivation and Engagement Scale (MES)	Self-belief (4 items)	"If I try hard I believe I can do my schoolwork well"
	Learning focus (4 items)	"I feel very happy with myself when I really understand what I am taught at school"
	Valuing school (4 items)	"Learning at school is important"
	Persistence (4 items)	"If I cannot understand my schoolwork, I keep trying until I do"
	Planning (4 items)	"Before I start a project, I plan out how I am going to do it"
	Study management (4 items)	"When I do homework, I usually do it where I can concentrate best"
	Disengagement (4 items)	"I have given up being interested in school"
	Self-sabotage (4 items)	"Sometimes I do not try at school so I can have reason if I do not do well"
	Failure avoidance (4 items)	"The main reason I try at school is because I do not want to disappoint my parents"
	Anxiety (4 items)	"When I have a project to do, I worry a lot about it"
	Uncertain control (4 items)	"When I do not do well at school, I do not know how to stop that happening next time"