THE DEVELOPMENT AND IMPLEMENTATION OF INTEGRATED SCIENCE TECHNOLOGY, ENGINEERING AND MATHEMATICS (STEM) INSTRUCTION IN THE MIDDLE SCHOOL SCIENCE CLASSROOM

by

CELESTIN NTEMNGWA

(Under the Direction of J. Steve Oliver)

ABSTRACT

This study was conducted to investigate the development and implementation of lessons that integrated technology objectives with science objectives (technology-based teaching idea) in a middle school science classroom to give students a STEM experience. To this end, this study examined and generated an account of the implementation processes, the nature of the instructional design, type of scaffolds, instructor’s support and adjustments to the learning environment, challenges teachers faced, the interaction among these teachers, and outcomes for students and students and teachers’ perceptions of the integrated STEM instruction.

The research questions that guided this study included (1) How do Science and Technology teachers restructure the middle school science curriculum and instruction in order to incorporate/implement STEM objectives into science classroom activities using a teaching approach emphasizing robotics equipment? (2) What are the teachers and student perceptions of the STEM implementation in regular science classroom? (3) What theoretical relationships are
discerned by the analysis of data? The qualitative data were collected from interviews and classroom observations then were analyzed using grounded theory methods, specifically the constant comparative method. The participants in the study included four middle school science teachers, a technology and 50 classroom observation sessions in eighth and sixth grades and interview of 13 eighth grade teams.

The results of study showed that for the implementation process, teachers spent more time on planning the integrated STEM instruction than on traditional instruction. They lacked prior experience in incorporating robotics into science teaching. The teachers did not revise their existing science curriculum; rather, they selected activities that fit into the science topics. The instructional approach used was student-centered. Integrated STEM instruction enabled students to apply science concepts to the project. Sixty percent of the students were motivated by the instructional approach and the nature of the activity; they were able to get immediate feedback while testing their robot, had the flexibility to work on any task on their own.

INDEX WORDS: Science education, STEM education. Integrated STEM education, Physics, Physics education, Curriculum and Instruction, Teaching and Learning, STEM Assessment, Robotics,
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DEDICATION

This work is dedicated to my entire family. Without their endless love and support I would not be where I am today. I also dedicate this work to my father, who supported me enormously, but did not live to see me finish my doctoral studies. In addition, I dedicate this dissertation research to my wife, Dr. Awungjia Leke-Tambo Ntemngwa for her love and support. You are the “wind beneath my wings.” And to my son, Jordan Ntemngwa who was born when I was in the middle of my doctoral studies and who has inspired me with his smile and energy. I love you very much!
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CHAPTER 1
INTRODUCTION

The call to improve science, technology, engineering, and mathematics (STEM) education has received national attention (Weber, Fox, Levings & Bouma-Gearhart, 2013). Improving the STEM education will lead to the enhancement of the workforce development and global economic competitiveness for the United States (Brown, Reardon, & Merrill, 2011; Herschbach, 2011; The President’s Council of Advisors on Science and Technology, 2011; Wieman, 2012). Among the proposed changes to improve STEM education are the calls for the integration of these STEM concepts and skills (Weber et al., 2013).

These calls have emphasized the need for improved curricula and instruction across the STEM subjects and even the abandoning of the specific disciplines for more integrated science courses (Herschbach, 2011). Others like Wachira and Keengwe (2011) have asked for specific STEM disciplines to be integrated like the call for the incorporation of technology into the instruction particularly in science, technology, engineering and mathematics (STEM) education. The National Research Council in its report on “Successful K-12 STEM Education” called for “increased STEM literacy for all students, including those who do not pursue STEM-related careers or additional study in the STEM disciplines” ((NRC, 2012, p.4). Also, both the Common Core State Standards for Mathematics (CCSSM) and the Next Generation Science Standards (NGSS) proposed more and deeper connections among the STEM subjects (National Academy of Engineering and National Research Council, NAE & NRC, 2014, p. 1). The NGSS clearly
stated that science teachers would have to teach both science and engineering objectives in an integrated manner (NAE & NRC, 2014, p. 1).

All of these appeals for change in policy, instructional approach and curricula are based on the premise that integrated STEM instruction makes learning more meaningful, connected and relevant to students (Stohlmann, Moore, & Roehrig, 2012). In reaction, several new instructional materials, programs, and specialized schools that integrate STEM are emerging (National Academy of Engineering and National Research Council, NAE & NRC, 2014). The NAE & NRC (2014) claimed that:

“Historically, US K–12 STEM education has focused on the individual subjects, particularly science and mathematics… The relatively recent introduction of engineering education into some K–12 classrooms and out-of-school settings and the 2013 publication of the Next Generation Science Standards, which explicitly connect science concepts and practices to those of engineering, have elevated the idea of integration as a potential component of STEM education” (p. viii).

The above claim underscores the need for STEM education to be taught in an integrated manner in our K-12 schools. The NAE & NRC (2014) further declared that teaching STEM in an integrated way makes “the STEM subjects more relevant to students and teachers” (p.1). A benefit the NAE and NRC proposed for advocating integration is an increase in STEM literacy. The National Science Education Standards, (National Academy of Sciences, 1996) defined STEM literacy “as the knowledge and understanding of scientific and mathematical concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity for all students” (p. 4). This definition is limited to science and mathematics concepts because the report focused on these two disciplines, but STEM literacy
would extend this definition to include the understanding of all the additional STEM disciplines of technology and engineering.

When it comes to technology integration, though there has been an upsurge in technological resources for instruction in schools (Culp et al., 2005). Nearly all schools have access to some form of technology like computers and smart boards, and technology-based modeling environments. Coupled with the claimed benefits that these instructional technologies can offer, like supporting curricular goals, it is essential to continue to research methods that can facilitate the process of incorporating instructional objectives and technologies into the K-12 STEM classrooms. In my recent observations, it seems as if some new technologies like robotics are frequently used in middle schools to introduce students to technology and engineering practices.

Based on the numerous definitions of integrated STEM education found in the literature of integrated STEM education (which I will discuss later in chapter two), the various integrative STEM approaches that have been used, like the integrative approaches as defined by Sanders (2009, p.21), and the results of my study I developed my own definition of integrated STEM instruction. In this study, I define integrated STEM instruction as a pedagogical approach in which concepts and objectives from two or more STEM disciplines are incorporated into a single project, so that students are exposed to the connections among and across these concepts and/or practices, learn or apply the concepts simultaneously rather than in isolation and relate them to real life situations. In this way, students could learn to apply these concepts in authentic real life problems, which are integrated in nature and may also acquire some 20-first century skills like problem solving. Students who participate in integrated STEM projects may be exposed to practices and content from various STEM
disciplines simultaneously, though these might not be explicitly stated or identified in the plan of instruction. From the literature on integrated STEM education, there is very limited effective approaches that can be used to design and implement integrated STEM instruction (National Academy of Engineering (NAE) and National Research Council (NRC), 2014, p.77). Therefore, it is important that as teachers implement an integrative unit or project in STEM education, the process should be well understood and documented for the rest of the STEM education community. Then the results can be transferred or adapted to other STEM settings or contexts. Documentation with particular emphasis on the nature of the integration process, how teachers scaffold the instruction and the outcomes of the integrated STEM instruction on students and teachers is necessary. This research study will focus on this documentation process.

I seek to characterize and analyze the implementation process that middle school science and technology teachers undertook in order to implement the Lego Mindstorms software and hardware in this research study. Lego Mindstorms is a new technology that is being introduced into their middle school science classroom in order to give students an integrative STEM experience (expose them to what experts in the field of STEM do). It enables researchers and to examine the perspectives (about integrated STEM instruction) of the teachers and students in the study. In so doing, particular attention is paid to the nature of the projects, the implementation process and the assessments used. The teachers involved in this study had to integrate technology and science objectives in a single project in order to give students a STEM experience using the robotics equipment or kit.

According to the Lego education website, the Lego Mindstorms is a series of kits, which include software and hardware to design small, customizable and programmable robots (http://www.lego.com). The company that designed the kit continues to design new versions. The
current kit is called EV3 kit; the previous was called the NXT kit. This study was particularly focused on documenting, examining and analyzing the implementation process, and the perspectives of both students and teachers, with the goal of developing a pedagogical theory that can be adopted for other integrative STEM settings.

Analysis focused on the core components of the teacher style (goals, practice, types of the scaffolds, assessment and views of the integrative project) teacher-teacher interaction or collaboration, teacher-student interaction, challenges or barriers the teachers faced, how they resolved these challenges, any transformations they enacted as they implemented and refined their strategies for use of this new technology. Goals included teaching computer programming in the middle school science classrooms, engaging students in engineering design, enhancing student problem solving skills, fostering cooperative learning among students and most importantly exposing them to STEM education by helping them make connections among STEM subjects and concepts. The study contributes to the literature on the benefits, limitations and strategies of integrated STEM implementation and how to use this technology to inform decision-making in STEM instruction.

This technology was new to the science classrooms in this school and as a result, the teachers started off without a well-defined goal of what to do, limited experience in this area, and very limited technology content knowledge but they were determined to try it. The school had the ultimate goal of giving students a STEM learning experience and believed that this could be accomplished by integrating technology into their regular science classroom instruction. This was derived in part from the success their students working on this technology, mostly as club or after-school activity have shown. In this study, I documented and analyzed the transformations these teachers undertook as they moved from vague goals or theoretically driven practices to a
clearer goal. I documented support they received, the ideas for project sources, assessments and their overall impressions and perceptions about this instructional approach. I observed classroom instruction and interviewed students and teachers to get their viewpoints on integrated STEM instruction. Then I analyzed the process to come up with knowledge claim or pedagogical theory that others can use in their integrative STEM context.

To accomplish this objective, I employed the constant comparative data analysis method (Glaser & Strauss, 1967). Some aspects of the design-based-research approach (Design-based research collective, 2003) were used to capture fine details of any iterative process. Reasons provided for making changes (if any) in the implementation process were documented. How the integrated STEM project was implemented or the instructional approach, any evidence of the impact of this integrated STEM instruction on student learning and practices were recorded. Some practices observed were science inquiry, engineering design and more active engagement in the learning process. Observation of instructional sessions and conducting teachers and student provided access to student achievements or outcomes (as defined and assessed by the teachers or expressed by the students) within the process. I conducted mini-interviews as the students engaged in the integrative STEM unit or project and I looked at their artifacts and asked them to explain what they did. All of this data was analyzed with the goal of developing a pedagogical theory or framework to offer recommendations that will help to direct future implementations of integrative STEM classroom instruction.

As Confrey (2006) noted, when multiple realizations are carried out, they could generate some ideas that may inform decision-making. Multiple realizations here mean to take place in different settings at different times. The implementation of this new technology involved multiple realizations or implementations in the school. The technology was implemented
successively in fifth through eighth grades, although not all of these grade groups were available to be part of this research. Teachers who implemented the study were available to talk about what they did, even if their students were not involved in the research. These multiple implementations (sixth and eighth grades) provided some ideas that could guide for the pedagogical theory and decision-making about technology integration in the STEM classroom and integrated STEM education in general.

**Background Knowledge**

There is a dearth of a common definition of integrated STEM instruction in the literature on technology integration in the STEM instruction. This contention goes to support Belland (2009) ‘s claim that there is no common definition of the term. Technology integration in the STEM classroom can take various forms that typically fall under the global topic of model-based learning. There are various forms that model-based learning can take in an instruction setting, some examples include: students manipulating, sharing, and using models to represent and elucidate scientific concepts and phenomenon; using the internet to explore and gather information about a scientific process or phenomenon; using PowerPoint presentation, and introducing a new technological tools like robotics kit that can help students learn a new idea and design artifacts (Church et al, 2008). All of these are examples of model-based learning and constitute technology integration in the classroom.

The framework for K-12 Science Education (NRC, 2012) defined technology as “any modification of the natural world made to fulfill human needs or desires” (p. 202). We know that science is the study of the natural world, which implies that there is an interdependent relationship between science and technological development or an interdependent among STEM disciplines in general. In his article “Engineering design in the classroom: Is it good science
educational or is it revolting?” Carlsen (1998) asserted that engineering design in the classroom is
good for teaching science education because technological design projects offer a “
sociologically fruitful approach for teaching new themes in science education” (p.51). Layton
(1994) stated that science educators continue to raise the question of whether technology-
centered activities provide a learning environment that enhances the scaffolding of student
learning of science. While there are many positions as to the relationship between technology
and science learning (Schon, 1993; Fensham & Gardner, 1994), it is important to note that
“science and technology are deeply related domains, are part of a (semiotically) seamless web
that integrates any distinction” (Roth, 2001, p.769). This assertion by Roth (2001) underscored
the necessity for viewing technology education and science education as an integrated unit. In
contrast with the common held belief, technology education is not just about incorporating
computer literacy into the curriculum (Hannover Research, 2011). According to Thornburg
(2008), technology education should be extended to involve various devices, instruments, and
tools, which can be applied in both fields of science and engineering.

Despite the various connotations attributed to technology integration in the classroom, they
all seem to have among other things, a common purpose which is to improve teaching and
learning in the classroom (Lefèbvre, Deaudelin & Loiselle, 2006) and in STEM education.
Technology integration can also support effective communication between teachers and students
(Dawes, 2001), enhance student achievement (Bransford et al., 2000); boost teachers’
pedagogical practice (Bingimlas, 2009) and provide students with opportunities to develop
workplace skills (Grimus, 2000; Yelland, 2001). Other researchers contend that using computers
as a component of classroom instruction could help students become knowledgeable, and give
the teacher more time to assist students with individual needs (Romeo, 2006). Also, Ertmer,
(2005) found that technology could assist students in solving problems. Lam & Lawrence (2002) claimed that it gives the learner the opportunity to control their own learning process and access to an enormous amount of information over which the teacher has no control. It is important to note that my research does not just focus on technology as a tool but as a discipline in STEM. My study considers technology as a part of the STEM integration instruction, and explored whether teachers make explicit the technology objectives that they want the students to attain, which is the case in this research study.

Access to technological resources like computers in school has increased significantly in recent years (Gray, Thomas, & Lewis, 2010). According to Gray et al (2010), a survey based on a National Center for Education Statistics (NCES, 2010) indicated the following key findings on teachers’ use of educational technology in public schools during the winter and spring of 2009. Seventy nine percent of teachers had one or more computers located in the classroom every day, while fifty-four percent could bring computers into the classroom. Internet access was available for ninety three percent of the computers located in the classroom every day and for ninety six percent of the computers that could be brought into the classroom. The ratio of students to computers in the classroom every day was 5.3 to 1. On the other hand a lot of applications of technology hardware and software and other technology-related devices like Lego Mindstorms kit continue to emerge and occupy a primary role in the STEM education (www.lego.com). Researchers in STEM education are still actively calling for effective ways to implement integrated STEM instruction and are reiterating the fact that the integrative nature of STEM disciplines has not been noticeable (Weber et al, 2013). This warrants more research, particularly on how this implementation can be done and how to successfully incorporate it into a school curriculum.
Overview of the study

This study was conducted at Alpha Academy (pseudonym), an independent privately funded school located in southeastern United States. The administration decided to incorporate a new technology, the robotics Lego Mindstorms using the EV3 kit, into the middle school science (fifth through eighth) instruction in order to give the students a STEM experience. The middle school science and technology teachers collaborated to implement this technology. The teachers implementing this collaborative instruction were seeking ways to use this technology (robotics) as a means to integrate technology objectives into their science curriculum and instruction. They selected topics based on their curriculum and syllabus and which could serve as a means to combine the science and technology objectives in their instruction. Some topics the teachers used included:

- Kinematics concepts like velocity and acceleration in eighth grade physical science with coding
- Biomechanics (body forward) in sixth grade life science.
- Astronomy- asteroid exploration in seventh grade

Initially the teachers did not have a well-defined approach of how to incorporate technology objectives into the science curriculum and instruction. They believed that there would be some changes in the process, and on the spot learning to help them attain their objectives. By change in the process, I mean that they would make changes to the process as they proceeded with the implementation of the technology, teachers would learn from each other and those who had not yet implemented it would learn from those who had.
During the fall semester of 2013, collaborating teachers started the implementation process, beginning with seventh and fifth grades. I attended some of the planning and training sessions with the teachers prior to the implementation, hoping to learn how the robotics kit could be used in the middle school science classroom. This meeting also gave me the opportunity to meet with some of the middle school teachers. Some of the teachers became very interested in incorporating the robotics in their science classrooms during training, because I heard them express their belief in the potential benefits of that approach. During the study, I observed the classroom sessions, interviewed students during the implementation and teachers after the implementation to find out if they actually benefited from this project and also to understand their perspectives on this integrated STEM instruction. The data collected included the observation notes and interview transcripts. These data were analyzed using the constant comparative method.

The goal of this study was to gain further understandings about how science teachers collaborate with the technology teacher to implement a new technology in middle school classroom that combines technology and science objectives to give students an integrated STEM experience while focusing on the “why”, “how”, “when” and “what” of the implementation process and detailed documentation of the implementation process. To do this, I document the execution of the process in greater detail with a particular focus on the nature of the implementation and how it was supported, the outcomes (types of scaffolds, the assessment and the effect on student learning as viewed by the teachers and students themselves). The objectives of my study are: (1) to gain insights on science teacher’ philosophical orientations or perceptions on integrated STEM education; (2) to search for patterns between practical implementation of technology objectives with science objectives in STEM and the theory of integration in STEM;
(3) to report the outcomes of the implementation explore the iterative process of technology objectives integration in STEM.

**Statement of the problem**

Technology integration in the STEM classroom in particular has come with several benefits; for example, it expands the pedagogical resources available to science teachers (Al Alwani, 2005), and assists students (provide them with hands-on authentic activities) in their learning (Balanskat, Blamire, & Kefela, 2006). However, technology integration in the science classroom and in STEM in general, continues to pose many challenges, is a complex process and can encounter a number of difficulties (Bingimlas, 2009, p.237). It is not that easy to figure out how to use the numerous technologies to effectively combine technology objectives like programming to science objectives in the classroom. From my viewpoint, I believe this is due in part to the fact that classrooms are complex learning environments as students are influenced by multiple local variables like the social, physical and psychological factors. This follows Cobern (1993, p.108) assertion that students could hold different interpretations due to their different background of knowledge. To make matters worse, each classroom and its students are unique, so combining technology objectives and science objectives in a science classroom has to be contextualized, which poses the problem of generalizability. It is therefore important that in a study like this one, I document the details of any outcomes and the implementation process in order to shed more light on the nature how integrated STEM education could be conducted. Providing the detailed analysis of the process and outcomes of the implementation of integrated STEM education could benefit those who will want to implement integrated STEM education in their own classroom (NAE&NRC, 2014). Hence, they can easily figure out what to retain, modify or eliminate before replicating the same process in another setting. Technology
integration in the classroom has also been affected by a lot of barriers or challenges both at the teacher’s level and school level (BECTA, 2004). Among those barriers are insufficient knowledge and skills (Pelgrum, 2001), lack of content knowledge, fear of failure, lack of confidence, and lack at of time for implementation. As I perused the literature on integrated STEM education, I realized that there is actually no clear iterative process or theory or framework on how to go about implementing technology objectives in a science classroom, especially showing the students the connections between and among these disciplines.

However, analyzing and documenting the detailed implementation process that these teachers in this study used and how and the students did could help shed more light on the problem/barriers; the nature of the implementation, the types of scaffolds used and the outcomes of the integrated STEM instruction. The analysis of the process of implementation could lead to a knowledge claim which could provide some assistance to teachers to support build their understanding of conducting integrated STEM education like using this technology (Lego Mindstorms) or other technology to combine technology objectives with science objectives in STEM education. At Alpha Academy, the teachers and the administration have an interest in seeing the Lego Mindstorms implemented in the classroom, to give students a STEM experience. However, they do not actually have a clear strategy or understanding of how to go about it, yet are determined to work together in order to get the project up and running in the classroom. This research examined what happens when (1) teachers implement the technology to integrate STEM content, (2) how they handle any barriers or challenges, (3) resolve any differences in opinions, and (4) the iterative process (if any).
**Rationale**

This study was conducted to investigate the development and implementation of lessons that integrated technology objectives with science objectives (technology-based teaching idea) in a middle school science classroom to give students a STEM experience. This study focused on how teachers can provide quality and effective implementation of integrated STEM education in the Middle School science classroom. It is aimed at examining and generating an account of the implementation processes, the nature of the instructional design, type of scaffolds, instructor’s support and adjustments to the learning environment, challenges teachers faced, the interaction among these teachers, and outcomes for students. The purpose is to develop the relationship or links between the various components of the integration process a pedagogical theory or knowledge claim, which could guide subsequent development and implementation of integrated STEM education or instruction, and informed decision-making on technology integration in STEM education to improve student learning in science and other STEM disciplines. In order to develop such a theory, I documented the detailed account of the implementation process (from preparation to assessment), asking questions along the way and gathering evidence of any intermediate achievement(s) and other outcomes.

Educational practitioners, students, researchers, curriculum developers, and school administration could benefit from this research, by using the results to inform their decision-making on STEM integration and particularly the integration of technology and science objectives in a STEM classroom using robotics. The technology (robotics especially for education purpose) designers could also use the result of this study to inform subsequent hardware and software design modifications. The participating teachers could equally benefit from this study by using the results to reflect on the
implementation process and possibly making adjustments on the way they will conduct similar lessons on integrated STEM education in the future. The school administration could use the results to understand some of the challenges that the teachers faced and think of ways to help provide more support to the teachers.

**Research Questions**

The purpose of this study is to examine the implementation process with the intention of developing a pedagogical theory. It is important that I document every detail or refinement and understand the reasons why teachers make changes in the process as they implement the technology in the classroom and understand teachers and student perspectives on this integrated STEM instruction. Therefore, the results of the study presented here are an attempt to answer the following research questions:

**How do Science and Technology teachers restructure the middle school science curriculum and instruction in order to incorporate /implement STEM objectives into science classroom activities using a teaching approach emphasizing robotics equipment?**

In this question, I am looking at the features of the restructuring and the implementation process, which includes the transformation from a not so clear goal to a somehow clear goal, focusing on any intermediate corrections or modifications with explanations why they are made. The transformation includes tasks related to the curriculum, interactions with students, intermediate goals and what evidence they use to refine their ideas. Other features of the restructuring and implementation process that I examined include the challenges or barriers that the teachers encountered, how they confronted those challenges and their approach toward implementation of integrated STEM instruction, particularly the nature of the implementation approach, the types of scaffolds, the assessment and any impact on student learning.
As discussed in the introduction, and background sections of this paper, there are still several barriers that hinder the effective implementation of technology integration in the STEM classroom. I was interested in finding out if those barriers would apply in this case and if new ones would emerge, and if so, how did these teachers or the school administration solve them. I also examined any differences in opinion among these teachers and how they reconciled them in order to achieve their common goal.

**What are the teachers and student perceptions of the STEM implementation in regular science classroom?**

In this question, I was focused on finding out if the implementation of this new technology benefit or does not benefit the following:

- Instruction in that course
- Student learning, as perceived by the teachers and the students
- Student motivation. Here, I am looking at how it impacts student intention and interest to do STEM integration in the future and their science learning. Observing the classroom instruction and conducting mini-interviews as students engage in the project and interviewing teachers would provide data to answer this part of the question.

Also, how does it change?

- Teachers’ Knowledge about teaching integrated STEM units
- Teachers’ attitude about teaching the particular integrated unit
- Teachers’ intention for future teaching

According to Kanuka et al. (2013), “the importance of recognizing philosophical viewpoints comes to light when examining debates and disagreements revolving around related practices
and policies.” This means that teachers’ beliefs have an impact on practice (Kane, Sandrello & Heath, 2002).

**What theoretical relationships are discerned by the analysis of data that are gathered?**

Here, I am focusing on using the information gathered from the practical implementation of this new technology to illuminate the theory on technology integration in STEM in order to develop a pedagogical model or framework of technology integration in STEM education.

As I studied the process of implementing this integrated STEM lessons, I gathered fine details, which could provide some trends on how similar technology can be integrated in the science classroom to give students a STEM experience in other settings.

**Significance and Scope of Research**

Completing this study would show how practical implementation of integrating technology objectives in STEM could illuminate the theory for integrated STEM education implementation. The understanding of the relationship between practice and theory will help to create a model for technology integration in STEM instruction in particular and STEM integration in general. For theory, this study is an addition to previous studies on technology integration in the STEM classroom practice because it focused on examining the nature of the implementation of STEM integrated-based teaching approach. In addition, it utilized data from an actual middle school classroom where the science teachers collaborated with a technology teacher to implement integrated STEM instruction. It this way it contributes to the literature of STEM integration with its benefits, challenges, nature of implementation and the outcomes of the implementation to both students and teachers.
In practice, this study is significant as it shows how technology objectives and science objectives could be combined in a lesson in which students to utilize practices like engineering design and skills like problem solving in order to accomplish an assigned task. Results could indicate examples of the relationships or connections among and between concepts and/or practices from STEM disciplines like the connection between acceleration, velocity, speed and coding or acceleration, engineering design and coding. The results could also be used to inform the scale up of the implementation and assessment in integrated STEM education because these areas still pose a lot of challenges to the success of integrated STEM education (NAE &NRC, 2014). It could assist practitioners, researchers, designers and administrators to improve decision-making on the what, the how and the why of combining technology and science objectives in STEM education to enhance student’s STEM experience.

**Theoretical framework**

My theoretical framework for this study is the social constructivism. Social constructivism framework shapes “the meaning of research questions, the purposiveness of research methodologies, and the interpretability of research findings” (Crotty, 1998, p.17). Vygotsky’s (1962, 1978) social development theory and zone of proximal development (ZPD) theory constitute the most important foundation of social constructivism. According to these theories, social interaction plays an essential role in the development of cognition. ZPD which is one of the most influential concepts of Vygotsky’s (1978) theories is defined as the difference between the difficulty level of a problem a child can cope with independently and the level that can be attained with adult assistance (Bruning, Schraw & Ronning, 1999). Also, social constructivism accentuates the significance of culture and context in understanding what happens in society and building knowledge based on this understanding (Derry, 1999). These lead to
assumptions of social constructivism (Kim, 2001). The first assumption is that learning is a social process, which does not take place only within an individual nor just a passive development of behaviors that are shaped by external forces (McMahon, 1997). Rather, when individuals are engaged in social activities, meaningful learning occurs (Kim, 2001). With this view in mind, I had to observe student group interactions in the classroom and interview them as they worked on their group projects. The second assumption is that knowledge is a human product, which is socially and culturally constructed (Ernest, 1999). When individuals interact with each other and the environment they live in, they create meaning (Kim, 2001). Social constructivists also view social context to have large affect on the nature and extent of the learning (Gredler, 1997). They placed much importance on the nature of the learner’s social interaction with knowledgeable members of a particular the society because the interactions help the learner to acquire social meaning of important symbol systems like language, logic, mathematical systems, among others (Kim, 2001). Furthermore, Kim (2001) argued that social constructivists value both the social context that learners bring to the classroom and the context in which learning occurs. It is based on these views that I considered classroom observations and student perspectives an essential part of this study. Another perspective of social constructivism on learning is the cognitive tools perspective (Kim, 2001). This perspective centers on the learning of cognitive skills and strategies. This learning occurs when students are engaged in activities that involve hands-on project-based approaches and the use of discipline-based skills (Gredler, 1997). When these learners work on the project together, they could produce some product which the group impose meaning on through the social learning process (Kim, 2001). This supports the claim that learning occurs when we make sense of what is experienced and not
by transmission (Cobern, 1993). Also, Learning theorist Ausubel asserts that meaningful learning is the only real learning (Cobern, 1993, p.103).

However, I also take a pragmatic approach to social constructivism, viewing it as a description of learning that can subsequently guide teaching. In terms of this pragmatic approach, I am in support of the assertion that knowledge, meaning, and understanding of the world can be adopted in the classroom from both individual learner and the shared view of the whole class (Gredler, 1997; Cobb, 1995). Cobern (1993) also argued that construction and meaningful learning could help make sense of the extensive knowledge occurrence among individuals. Social constructivism stresses that fact that meaning making should not be limited to the individual mind but to the “outward to the world of intersubjectively, shared social constructions of meaning and knowledge” (Schwandt, 1994, p. 127). Students could hold different interpretations of concepts like science concepts due to their different background of knowledge (Cobern, 1993, p.108). Students could also construct knowledge using their existing knowledge. Also, from the social constructivist perspective, knowledge is constructed in student minds using social interactions. Therefore social interactions could encourage or restraint the knowledge construction (Driver, Asoko, Leach, Mortimer, & Scott, 1994). This is when scaffolding is necessary to provide guidance.

I used these social constructivist perspectives on knowledge construction to guide this research study. First, I endeavored to take into consideration the actual teaching environment in which the teachers who participated in this research study worked when I investigated their implementation strategy. Also, knowing that teaching and learning go together. In other words, teacher’s instructional strategy is influenced by the teaching contexts where there is interaction between teachers and students, I lay emphasizes on the interaction between the teacher and
students. I also focused on the type of scaffolding that the teacher provided to the students because of the concept of the Zone of Proximal Development, ZPD, as mentioned earlier. Students would certainly need help as they work through ZPD levels. How does the teacher assist them navigate through these levels? Did the teachers help by providing hints or instruction? These are some of the questions that I considered during the classroom observations.

I also took into consideration, the fact that as students worked in groups, they use different perspectives that they have gained from their different backgrounds. These different perspectives can be used to help the group solve the problem more effectively. As a result, I designed student interview questions with this view in mind. It was also based on this views that I paid attention to reasons (if any) the teachers used to place students in particular groups.

In my view, the success of integrated STEM education is grounded on the premise that when teachers receive the necessary support, they would be more confident and better prepared to deliver integrated STEM instruction. Integrated STEM education needs teachers to be able to show students the connectedness of STEM concepts. These are areas where students need help because the students cannot spontaneously make these connections (NAE & NRC, 2014). The support they receive will enable them to design instructional activities that encompass the process of knowing in a way that let students interact in social context to develop meaning that is shared by the interacting students. Thus, “key aspects of mental functioning can be understood only by considering the social context in which they are embedded (Wertsch & Toma, 1995, p. 159). The support could help them be able to design more effective implementation, which includes better ways to scaffold student learning, and better assessment technique. This would thus provide students with a better learning experience and better outcomes of the integrated STEM education. Since learning occurs by interpretation and interpretation is facilitated by
discourse (Cobern, 1993, p. 110). It infers that activities that promote discourse (at the social level like working in teams) could enhance learning. In this theory, I view the teacher as a constructivist teacher who seeks to understand a student’s existing rational about a topic (Brooks & Brooks, 1993). The measurable outcomes will then be used to illustrate the importance of integrated STEM education, which may raise awareness and bring many more educators to implement it.

In order for the public to be aware of the importance of integrated STEM education, there is a need to document a detailed implementation process including instructional strategies, scaffolds, assessment techniques, and student outcomes (NAE & NRC, 2014). Also, teachers and student perceptions and impressions, teacher support, identified goals and outcomes, implementation strategies, and student prior knowledge maybe helpful. This may help to develop lessons that are appropriate and meaningful, contains appropriate scaffolding, better assessment techniques, and modification of implementation strategies in light of outcomes measured and the desired goals. Students could play an essential role in knowledge construction. This is the reason why I believe that understanding their perceptions of this integrated approach may help the teachers to provide more relevant and engaging activities that attract student active engagement and enhance their learning. These activities may have to be relevant and interesting while still embedded with the intended concepts that the students need to learn and apply.

Summary

In this chapter, I have discussed the purpose of the study, some background knowledge of technology integration in STEM, rationale of the study, statement of the problem, research questions and the theoretical framework that guided the study. In the next chapter, I describe the conceptual framework which guided the study, discuss some of the barriers of integrating
technology objectives in STEM and the value of educational robotics in schools. Furthermore, I discuss the definitions, features, goals, implementation approaches and the benefits of integrated STEM education in K-12 education. I did this through a review of relevant literature in these areas.
CHAPTER 2
LITERATURE REVIEW

There are numerous areas of the literature that helped to inform this research study. They include research on the educational value of robotics in secondary schools; studies of the benefits of integrated STEM education; and research that examines challenges, benefits and implementation approaches relative to the curriculum and instruction of science in secondary schools. These studies support the educational use of robotics to attain curricular goals and support how to design and implement educational robotics programs. The review examines integrated Science, Technology, Engineering, and Mathematics (STEM) education barriers affecting its implementation and some implementation approaches that have been used in middle schools. Beyond this the depth of this body of research will be examined in order to make any generalizations on how these reports of prior research parallel the present study.

STEM and STEM Education

The National Science Foundation (NSF) first used the acronym “STEM” in the 1990s. The NSF used this acronym to refer to programming dealing with science, technology, engineering and mathematics (Carnegie Mellon University, 2008). Even though NSF developed this acronym, it did not specify a clear definition for “STEM”. This lack of definition then led to a proliferation of differing definitions and operational applications across the country and among organizations (Hanover Research, 2011). These definitions though not necessarily discordant with each other have generated a multitude of interpretations, which have led to the creation of confusion among educators. Bybee (2010) asserted that STEM has been used in a general sense
to refer to an event, policy, program or program that has to do with one or more of the STEM disciplines. As I perused the literature on STEM and STEM education, I have realized that STEM and STEM education are often used interchangeably. However, I do believe that these are two different concepts and I have treated them as two concepts with different meanings in this study. In this study, I used STEM as an acronym for science, technology, engineering and mathematics. Whereas, STEM education to me, is the process of receiving or giving methodical instruction in the STEM disciplines. The instruction could be focused on a single STEM area like science or on two or more of the four areas at the same time.

Basham and Marino (2013) viewed STEM education to “represents a symbiotic relationship among the four interwoven fields.” (p. 9). This definition of STEM education stressed the interdependence of the four disciplines, and the integrated approach to teaching science, technology, engineering and mathematics. This interdependent nature of STEM fields led to the idea of integrated STEM education. Integrated STEM education or instruction is designed to engage students and increase motivation especially using project-based learning (Laboy-Rush, 2011). It encourages students to solve authentic problems and asks them to work with others to build real solutions. STEM initiatives have been shown to improve test scores in math and science and prepare students for college and career (Becker & Park, 2011). So, there are three important terms that have been used in this section: STEM, STEM education and integrated STEM education. In this study, I defined STEM as an acronym for science, technology, engineering and mathematics: STEM education as the process of receiving or giving methodical instruction in the STEM disciplines; and integrated STEM education or instruction as a pedagogical approach in which concepts and objectives from two or more STEM disciplines are incorporated into a single project, so that students are exposed to the connections among and
across these concepts and/or practices, learn or apply the concepts simultaneously rather than in isolation and relate them to real life situations. In this way, students could learn to apply these concepts in authentic real life problems, which are integrated in nature and may also acquire some twenty-first century skills like problem solving.

Increasing importance of STEM education is indicated by the growing demands of global competitiveness and of the technology driven economy (NAE & NRC, 2014). According to The Committee on Highly Successful Schools or Programs for K-12 STEM Education of the National Academy of Sciences, National Academy of Engineering and the Institute of Medicine (2011):

“The primary driver of the future economy and concomitant creation of jobs will be innovation, largely derived from advances in science and engineering . . . 4% of the nation’s workforce is composed of scientists and engineers; this group disproportionately creates jobs for the other ninety six percent” (p.4)

Our world is quickly changing. Nonetheless, it is startling to hear that the top ten in-demand jobs in the US in 2012 did not exist in 2004 (Casserly, 2012). The rate of change is accelerating and today's students need to be adaptable and prepared. STEM education, with its emphasis on applying knowledge and building twenty-first century skills, helps educators meet these challenges (NAE & NRC, 2014). In middle schools, STEM education is done in a collaborative manner (NAE & NRC, 2014). It attempts to help them develop skills like critical thinking, creativity and innovation. It relates conceptual learning to meaningful real world applications and creates interest and enthusiasm for careers in STEM fields.

This section of the chapter has focused on the brief introduction to STEM education and its importance. In the next section of this chapter, I will discuss the educational value of robotics
in schools because in this study robotics equipment were used in the science classroom. So, I found it useful to review what has already been done with robotics in the science classroom. Also, in the proceeding section I will examine some of the main issues in integrated STEM education, beginning with barriers or challenges (I used barriers, obstacles and challenges to mean the same thing in this study) affecting integrated STEM education.

I will discuss more about integrated STEM education later in this chapter. First, I would examine educational robotics (I used educational robotics in this study to refer to robotics that are used in schools for educational purpose) in the classroom because my study involved the use of robotics equipment in the science classroom for integrated STEM instruction. I will review some studies that examined the value of educational robotics and how robotics is used to support knowledge construction STEM education and science education in particular.

**Educational Robotics: Their Value in Schools**

Since Seymour Papert’s introduction of robotics into the education milieu in 1980 (Papert & Harel, 1991), the question that has remained is whether to integrate educational robots into the curriculum of science and technology, or to confine them to extracurricular activities (Arroyo, Arroyo & Schwaartz, 2003). Even though research has revealed that there has been an increase in the popularity and commercial market for robotics (Kara, 2005), there has been very limited research conducted to show the impact of robotics on K-12 student learning (Williams, Yuxin, Prejean, Ford & Lai, 2007). These researchers argued that a possible reason for such lack of robotics activities in schools could be because of the absence of empirical evidence to support their impact on curricular goals. Also, most of the literature on the impact of robotics activities in schools is descriptive and based on subjective evidence (Ford, Dack & Prejean, 2006). Few studies have actually used qualitative or quantitative method to study the effect of robotics
activities (Baker & Ansorge, 2007; Petre & Price, 2004; Robinson, 2005). This thus raises the need for more empirical evidence to help educators understand the benefits of robotics activities on curricular goals (Williams et al., 2007). My research would add to literature of robotics in the classroom because it examined how integrated STEM instruction is implemented in the middle school classroom using robotics equipment. Papert and Harel (1991) and other educational theorists believed that robotics activities could tremendously improve classroom teaching and learning. For example, robotics projects were shown to have a positive effect on science and technology motivation in the classroom (Barker & Ansorge, 2007; Carbonaro, Rex, & Chambers, 2004). Petre and Price (2004) also found out that robotics have a positive effect on the level of collaboration between students, and on student problem solving and critical thinking skills.

Williams et al. (2007) contended that the limited implementation of robotics projects in schools is due to the lack of practical or empirical evidence that reveals the effect of robotics activities on curricular goals. For this reason, these researchers set out to investigate the impact of a summer robotics camp on middle school student physics content knowledge and scientific inquiry skills. Williams et al. (2007) studied the effects of a two-week robotics summer camp on middle school student physics content knowledge and scientific inquiry skills. During the two-week of the project, students worked in small group on hands-on activities, and also participated in-group discussions. Participants in this study included twenty-one middle school students who registered in the robotics summer camp and ten facilitators. The summer camp participants were administered a pretest and posttest. The pretest and posttest questions investigated factual knowledge and scientific inquiry knowledge. The physics content knowledge measure consisted of twelve multiple –choice items developed by the research team and was aimed at assessing student understanding of Newton’s laws of Motion. The scientific inquiry measure was made up
of five questions based on an instrument designed by Harvard Graduate School of Education researchers. The scientific inquiry measure used scenarios. Students were exposed to a scenario and then asked questions based on that scenario. The qualitative data came from facilitators’ focus group interviews, individual facilitator interviews, facilitator’s reflections and researcher’s field notes. Each participant received a factual knowledge measure and a scientific inquiry measure before and after the robotics intervention. The research then used a two tailed paired t-test to calculate and compare pretest and posttests scores on the physics content measure and a two tailed paired t-test to calculate and compare the pretest and posttests on the scientific inquiry measure. The results showed a statistically significant difference on the physics content knowledge measure from pretest to posttest, p=0.004. There was no statistically significant difference on the pretest and posttest scores on the scientific inquiry measure, p = 0.077. The researchers’ interpretation of the results was that the students have not followed the scientific inquiry because they were carried away by the “excitement and novelty of building robots” and this could make the design challenges less interesting. Also, “the difficulty of some challenges might not have encouraged explicit application of the scientific inquiry process” (Williams et al., 2007, p. 210). As for the physics content knowledge, they argued that the students benefited from the various robotics activities that gave them the opportunities to experiment with physics concepts. Also, the “short lessons, tutorials, and debriefings embedded in the problem solving activities might have helped the students make the connection between experience and scientific concepts” (Williams et al., 2007, p.208).

In another study, Barreto and Benitti (2012) reviewed published scientific literature on the use of robotics in schools in order to: (a) identify the potential contribution of the incorporation of robotics as educational tool in schools; (b) present a synthesis of the available
empirical evidence on the educational effectiveness of robotics as an educational tool in schools; and (c) define future research perspectives concerning educational robotics. The authors used the following criteria to determine which articles would be included in the review:

The article reports the application of robotics as a teaching tool; in other words, the objective is to use robotics as an educational means. Article must present educational robotics in an elementary, middle and high school context. Articles were included only if they presented a quantitative evaluation of the learning, observing the guidelines proposed by Kirkpatrick and Kirkpatrick (2006), who recommend carrying out tests before and after the training, to evaluate the learning. Finally an article should involve the use of physical robots.

Barreto and Benitti’s (2012) results showed that 80% of the studies explored topics related to the fields of physics and mathematics. The articles specifically reported experiences teaching Newton’s Laws of Motion, distances, angles, kinematics, graph construction and interpretation, fractions, ratios and geospatial concepts. The articles also highlighted skills that could be developed or improved through robotics, emphasizing skills in problem solving, logic and scientific inquiry.

In other studies, Petre and Price (2004) conducted interviews of students between the ages of six to eighteen who attended RoboCup competition and students between the ages of twelve to fourteen who attended RoboFest competition. RoboCup and RoboFest are robotics tournaments. The students reported that they learned programming (the researchers did not describe precisely how the learning occurred), how to manipulate the robotics hardware, and skills like problem solving and teamwork while constructing and programming robots. Baker and Ansorge (2007) carried out a study to determine the effect of an after-school robotics science
intervention on student (between the ages of nine and eleven) achievement in science, technology and engineering. They measured this achievement using a 24-item multiple-choice instrument. The results revealed that the pretest and posttest scores of students who were in the robotics science intervention improved significantly compared to those in the control group.

Papert and Harel (1991) argued that robotics have the potential to improve classroom learning. Papert used the constructionism approach to provide students the opportunity to interact with technologies (Papert & Harel, 1991). Duffy and Cunningham (1996) defined constructionism as a learning and instructional theory with its roots in the philosophical tradition of constructivism, and which emphasizes the active role of the learner in collaboratively constructing knowledge in a rich context. Rich context here means environment that promotes student engagement. Papert and Harel (1991) differentiated constructionism from constructivism by arguing that constructionism shares the constructivism’s meaning of learning, as “building knowledge structures” no matter the conditions of the learning. The authors further stated that this constructionist approach to learning would occur particularly in an environment where the learner is having fun or in a “playful” environment. In this felicitous context, the learner is consciously involved in constructing a public object be it a sand castle or a beach or a theory of the universe (Papert & Harel, 1991). Thus, Papert’s introduction of educational robotics was to offer such a “playful” environment for learners to consciously construct some public entity like the robot.

Despite their growing popularity, robotics activities are usually not found in many regular K–12 classrooms (Williams et al., 2007). Introducing interactive technology like robotics can help develop metacognitive competence in students and higher order thinking (Ringstaff & Kelley, 2002; Zibetti, Chevalier, & Eyraud, 2011), and could help to motivate and engage
students (Prensky, 2005). In addition, the educational potential of educational robots is closely related to learning methods allowed by a specific type of robot (Gaudiello & Zibetti, 2013). Therefore, teachers have the task of figuring the most appropriate teaching strategy for a particular robotics activity. When robotics activities are added to science classes, they could “provide students with opportunities to play “the whole game” and also get student involve in world science through design, construction and testing of their own experiments” (Church, Ford, Perova & Rogers, 2010, p. 47). Teachers have the responsibility for providing the students with necessary support like “create entry points for students appropriate to their learning progression” (Church et al., 2010, p. 47).

Church et al. (2010) contended that incorporating robotics activities into the science curriculum affords rich opportunities to engage students in real world science and enable them to develop conceptual understanding of physics principles through investigations, data analysis, construction and engineering design. It also helps students develop better problem solving, teamwork skills and become confident learners (Church et al., 2010, p.47). Based on Williams et al. (2007) claim that these studies are based on opinions, I believed my study would contribute to the literature on robotics in the classroom. My study examined student perceptions of integrated STEM education learning using robotics projects. Also, my study focused on both teachers and learners’ perceptions about integrated STEM education using robotics equipment.

**Classroom Structure: Grouping of Student in Lego Activities**

After exploring some studies that focused on the value of robotics in the classroom, I also examined the implementation of robotics in the classroom. Implementation of Lego Mindstorms and robotics in general often involves students working in groups (Cheng, Huang & Huang, 2013). Based on Cheng et al. (2010), I discerned that group formation or arrangement is
important when students have to do group projects involving robotics. These researchers found that group composition have an impact on student performance. The teacher might want to place students in groups following a particular criterion or just let students form their own groups. However, research has shown that the way students are grouped could have an impact on their interaction (Cheng et al., 2013). These researchers carried out a research to investigate how student group formation impact interaction and achievement in Lego robotics learning activities. The purpose of their study was to examine how grouping of students influence students interaction and achievement in Lego activities. Student interaction and learning activities and performance were collected through Lego Robotics. The quantitative generated were analyzed using ANOVA. Moreover, qualitative data from interviews, video recordings, and related documents offered evidences for explanation. The findings of this study indicated that Lego Robotics facilitated learning by providing group-based learning experiences. The grouping of students with a diversity of background resulted in differences in interactions and learning outcomes. In addition, Cheng et al. (2013) found that student gender, age, and family background were not related to their learning outcomes. The results also revealed that students who were in groups of the same gender significantly engaged in more communication than the groups containing more female than male students. Furthermore, the groups of underprivileged students communicated considerably less than the non-underprivileged groups during programming activities. Finally, for programming activities, more interactions between group members would lead to higher performance scores (Cheng et al., 2013).

Cognizant of Cheng et al. (2010) findings, in my study I examined the way students were arranged (student groups) in the classroom and asked the teachers the reasons why they made such group arrangement and the possible effect that it had on the student performance. I did not
measure the effect of student group on performance but asked the teachers during the interview to explain the reason for such arrangement.

**Barriers affecting the integration of Technology in STEM classroom**

Despite the numerous benefits that technology (like educational robotics technology) use in the classroom can offer, many educators continue to face challenges that prevent them from effectively integrating technology into the classroom and to STEM education (Wachira & Keengwe, 2011). Though there is an increase in the access to computer tools in schools, teachers’ use and integration of this technology to enhance student learning continues to decline (Wachira & Keengwe, 2011). Barriers here refer to something that prevents or slows down the effective implementation of technology in STEM classroom. In this study, barriers mean the same thing as challenges or obstacles. Barriers to technology integration have been classified into external (first order) or internal (second order) barriers (Snoeyink & Ertmer, 2001). First order barriers include lack of the technical support, and resource related issues (Wachira & Keengwe, 2011). Second order barriers can either be teacher-level or school-level (BECTA, 2004). Teacher-level barriers include lack of time, lack of confidence, resistance to change (Bingimlas, 2009), insufficient technology knowledge and skills, and difficulty in integrating technology in instruction (Pelgrum, 2001), beliefs and attitudes about teaching and technology and openness to change (Wachira & Keengwe, 2011).

Levin and Wadmany (2008) carried out a three year longitudinal study in which questionnaires, interviews, and classroom observation were used to explore teacher views on factors affecting their use of information and communication technologies (ICT) in the classroom and how these views reflect changes in teachers’ educational beliefs and actual classroom practice. They studied multiple case studies of teachers at one school. In the study
they found that information technology could change the way teachers function, think, and feel in their classrooms and that technology integration still needs effective ways of implementation. This study could provide another way of implementing technology in the STEM classroom and thus close this gap of lack of effective ways of implementation.

Teachers’ beliefs and perceptions can contribute to practice as well. Ertmer (2005) argued that teachers’ beliefs about technology use influences their willingness to implement it in their classroom. Kanuka, Smith and Kelland (2013) further contended that when educators knows his or her philosophy of teaching and technology, he or she has the ability to express not only what he or she is doing as educational technologists, but what they want to achieve with the technologies, and why. Levin and Wadmany (2008) proposed that teachers play a key role in determining how technologies should be used in the classroom based on how they perceive the use of technology in the classroom. It is important to understand teachers’ perceptions and perspectives on integrating technology in their classroom in order to figure out ways to make technology use more efficient and meaningful in the classroom. Levin and Wadmany (2008) found that during the study of classroom practice with ICT, some teachers did not just know how to use the computers, but actually added the knowledge to their repertoire. Almekhlafi and Almeqdadi (2010) argued that teachers believe technology is an integral part of the process of educating their students.

Most of these claims have not been verified in an actual classroom setting. In my opinion, teachers’ beliefs and perceptions could be a significant factor in how they introduce a new technology in the STEM classroom. It can affect teachers’ knowledge, attitude and action. These challenges affect science education scholars in two ways: a) there is an urgent need to understand how teachers can use integrated STEM to help students actively engaged in the scientific and
engineering practices; and b) by extension, science teacher educators are faced with the challenge of developing ways to help prepare pre-service teachers to teach using the new framework and assess student learning in integrated STEM based projects and topics.

In this section of the literature review, I defined STEM, STEM education and integrated STEM education. I consider educational robotics as integrated STEM based activities because educational robotics involved concepts from at least two of the four STEM disciplines. For example, Williams et al. (2010) studied technology and science (physics) in a single robotics activity or project. I have also discussed the value of educational robotics in the science classroom and some challenges that teachers faced with technology integration in the classroom. In the next section I will draw significant information from integrated STEM education literature, particularly its characteristics, approaches, benefits and challenges to its implementation in the classroom.

I also had to examine the literature on exploratory research in science education to find out how similar studies to mine have been conducted. I will now summarize some of those studies and will state what I have learned from their methodologies.

**Exploratory Studies in Science Education**

In an attempt to gain some insights into why studies in science education are qualified as exploratory and the methodologies used, I searched for some exploratory studies in the science education literature. However, most of the studies that I came across did not include reasons why it was qualified as an exploratory study. What made to select each study was the fact that the researcher(s) referred to their study as exploratory study in the abstract. What I learned is that exploratory studies in science education have adopted various methodologies. A majority of them are qualitative in nature while a few are mixed method research. The research did not
provide much insight into their methodologies, but most of them used the constant comparative method for their data analysis. Most of these studies are examples of studies that are similar to mine.

Simon, Erduran and Osborne (2006) investigated the teaching of argumentation in secondary science classrooms. The study involved a group of 12 teachers from different schools who attended a series of workshops to develop materials and strategies to support the teaching of argumentation in scientific contexts. Data were collected at the beginning and end of the year by audio-recording and video-recording lessons where the teachers attempted to implement argumentation. The transcripts from these recordings were coded and analyzed using the constant comparative method. The results showed that teachers’ use of argumentation developed across the year, the pattern of use was teacher-specific as was the nature of change. In another study, Simmons, Emory, Carter, Coker, Finnegan, Crockett, & Labuda, K. (1999) investigated how the perceptions, beliefs and classroom performances of beginning secondary science teachers related to their philosophies of teaching and their content pedagogical skills. The participants were ten beginning science teachers who were in their first year of teaching. Data came from teacher interview, and classroom performance measures by daily journal completed by the teacher. The researchers used the constant comparative method to consistently compared data to generate categories, and then triangulated until the categories and relationships among them were saturated and the characteristics of the teachers understood. The results showed that teachers possessed a wide range of philosophies, and the observers ‘reports of teaching practices contrasted starkly with teachers’ descriptions of those teaching practices.

In another study, Rivard and Straw (2000) investigated the role of talk and writing on learning science. The purpose for the study was to explore the effect of talk and writing as
distinct activities as compared to talk and writing as combined activities on the learning and retention of simple and integrated knowledge, and to describe the mechanism by which talk and writing mediate these processes. In their methodology, they collected data from classroom observations. The oral statements and written responses to each of the explanatory tasks were compared to locate patterns of interactions within the peer group.

Also, Ketelhut (2007) carried out an exploratory study to investigate data gathering behaviors exhibited by 100 seventh-grade students as they participated in a scientific inquiry-based curriculum project delivered by a multi-user virtual environment (MUVE). In order to examine the relationship between student self-efficacy on entry into the authentic scientific activity and the longitudinal data gathering behaviors, the researcher used individual group modeling strategy where an outcome measure was derived from certain indicators like the number of different places visited by each student during each visit to the website. Student scientific inquiry (which the researcher did not specify) was coded and analyzed using SAS PROC MIXED. Also, Chang and Weng (2002) explored the interrelationship between student problem-solving ability and their science-process skills in the area of earth science. Participants included 195 earth science students enrolled in four science courses at four high schools in Taipei city, Taiwan. The researchers used statistical analysis to show the correlation between student problem solving ability and their science skills. Semi-structured interviews were also used and the analysis of these interviews using the constant comparative method revealed that higher-level problem solvers performed better on the problem solving processes than the lower problem solver.

In another exploratory study, Abd-El-Khalick and BouJaoude (1997) carried out a study to describe the knowledge base of a group of science teachers in terms of their knowledge of the
structure of, function, and development of their disciplines, and their understanding of the nature of science. In their methodology, they collected data from teachers’ semi-structured interviews and questionnaire. But did not specify the data analysis approach they used. However, I deduced from the study that it involved constant comparative method.

Finally, Roehrig and Luft (2007) carried out a study to understand the constraints that beginning secondary science teachers experienced when implementing inquiry-based lessons. Data was collected from interview documents (demographic survey and open-ended questionnaire that captured the beginning teacher’s views on the nature of science), semi structured interviews about teaching and teacher beliefs and observations of practice (each learner was observed at least seven times). Case and cross-case revealed five constraints that impacted teachers enactment of inquiry-based instruction: an understanding of the nature of science and scientific inquiry, content knowledge, pedagogical content knowledge, teaching beliefs and concerns about management of students.

These studies do not have a standard methodology and mostly exploring areas where not much research has been conducted. This seems to follow from the fact that “exploratory research tends to tackle new problems on which little or no previous research has been done” (Brown, 2006, p.43). Similarly, Bogdan and Biklen (2007) argued that exploratory in education done because of limited research in that particular area. From the methodologies of exploratory studies mentioned in this section, they all seemed to have similar data collection approach (used multiple sources of data like observations and interviews). These are similar sources that I used in my own study. I realized after perusing the literature for exploratory studies in science education that most of the researchers do not provide a detailed account of their data analysis procedure. For example, Abd-El-Khalick and BouJaoude (1997) said, “All interviews were
audiotape recorded and transcribed for analysis” (p. 683) and did not provide any further insights into the analysis. I also learned from these exploratory studies (Abd-El-Khalick & BouJaoude, 1997; Simmons, et al., 1999; Rivard, & Straw, 2000; Chang & Weng, 2002; Simon, et al., 2006; Ketelhut, 2007; Roehrig, & Luft, 2007) that any qualitative data involved was analyzed using the constant comparative method. As a result I decided to use the constant comparative method in my own study. I also from these studies the researchers used exploratory study because there was a paucity of research in the respective areas they were studying. Likewise, in integrated STEM education, I realized after examining the literature that there is limited research in that area. Integrated STEM education has limited empirical research (NAR & NRC, 2014 So, I adopted an exploratory research approach. Table 3.0 shows some main features of these exploratory researches in science education (i.e. Abd-El-Khalick & BouJaoude, 1997; Simmons, et al.,1999; Rivard, & Straw, 2000; Chang & Weng, 2002; Simon, et al., 2006; Ketelhut ,2007; Roehrig, & Luft, 2007)).
<table>
<thead>
<tr>
<th>Study</th>
<th>Statistical Analysis</th>
<th>Qualitative data analysis: Constant comparative</th>
<th>Theoretical foundations</th>
<th>Classroom observation and interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rivard &amp; Straw (1999). The Effect of Talk and Writing on Learning Science: An Exploratory Study</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Abd-El-Khalick &amp; BouJaoude (1997). An Exploratory study of the knowledge base for science teaching</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Ketelhut (2007). The Impact of Student Self-efficacy on Scientific Inquiry Skills: An Exploratory Investigation in River City, a Multi-user Virtual Environment</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Simon, Erduran, &amp; Osborne(2006). Learning to teach argumentation: Research and development in the science classroom</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
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</table>
Integrated STEM Education

What is integrated STEM Education?

Over the past twenty years, scholarly journals, and articles in various STEM areas revealed many titles devoted to areas such as integrated instruction, interdisciplinary approaches, fused, trans disciplinary, and thematic teaching (e.g., Berlin & White, 1995; Brazee & Capelluti, 1995, Stinson, Harkness, Meyer, & Stallworth, 2009). Shoemaker (1991) suggested that there are "an equal number of terms to describe the various ways integrated instruction might be approached" (p. 793). Some researchers like Ellis and Fouts (1993) simply equate such terms as interdisciplinary curriculum and integrated studies. Others like Beane (1995,1997) who made the distinction between interdisciplinary and integrative curricula, see it from a different perspective. Associated with interdisciplinary approaches, Beane's (1993, 1997) view of curriculum integration differed fundamentally from school subjects. “Disciplines, especially reflected in school subjects, represent what he called the "hardening of the categories" (1997, p. 39). Beane (1993) further suggested that disciplinary boundaries should be moderated so that they are viewed in terms of individual contribution to a specific project. Integrative undertakings within the curriculum should draw knowledge regardless of whether it is from the school subject area or discipline with which it might traditionally be related (Gavelek, Raphael, Blondo & Wang, 2000). Other researchers seem to see it otherwise, asserting that, "interdisciplinary" preserves disciplinary boundaries while "integrated" does not (Gavelek et al., 2000, p.4). Also, Pring (1973, p.135) argued that integration includes the notion of unity among forms of knowledge and their corresponding disciplines. However, to Petrie (1992) "interdisciplinary" means a combination or blending of disciplines while "multidisciplinary" suggest the presence and preservation of boundaries across these disciplines.
Integrated STEM education can thus be understood as interdisciplinary education that seeks to combine science, technology, engineering, and mathematics in one course (Micah et al, 2011). Sanders (2009,p.21) defined integrative approaches as “approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and /or between a STEM subject and one or more other school subjects”.

With all the definitions of integrated STEM learning in the literature, what exactly is integrated STEM. According to the Barakos, Lujan and Strang’s presentation on STEM in 2012, STEM is:

• An interdisciplinary approach to instruction, which involves Science, Technology Engineering and Math and promotes learning in these areas, as well as preparation and motivation to students to pursue careers in these areas.

• Focused on practical applications & solving problems: “STEM teaching and learning focuses on authentic content and problems, using hands-on, technological tools, equipment, and procedures in innovative ways to help solve human wants and needs.” (Merrill, 2009)

• STEM is a “meta-discipline.” According to Brown, et al. (2011), a meta-discipline is “a standards-based, meta-discipline residing at the school level where all teachers, especially science, technology, engineering, and mathematics (STEM) teachers, teach an integrated approach to teaching and learning, where discipline-specific content is not divided, but addressed and treated as one dynamic, fluid study.” Merrill (2009) also refer to “STEM teaching and learning as one that focuses on authentic content and problems, using hands-on, technological tools, equipment, and procedures in innovative ways to help solve human wants and needs” (p.6).
The above illustrate the use of STEM, STEM education and integrated STEM education interchangeably. This could create confusion on the proper conceptualization of these three concepts, which I consider to have different meanings. In my opinion, the author is defining integrated STEM and not just STEM.

Table 2.1 summarizes some major definitions (terminologies) of integrated STEM from the literature
Table 2.1

Summary of Major Terminologies Used to Define Integrated STEM Education

<table>
<thead>
<tr>
<th>Terminology used</th>
<th>Author(s)</th>
<th>Description/features</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• All teachers, especially STEM, teachers, teach.</td>
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<tr>
<td></td>
<td></td>
<td>• Discipline-specific content is not divided, but addressed and treated as one dynamic, fluid study</td>
</tr>
<tr>
<td>Curriculum integration</td>
<td>Fogarty and Pete (2007)</td>
<td>• Interwoven, connected, thematic, interdisciplinary, multidisciplinary, correlated, linked and holistic</td>
</tr>
<tr>
<td>Interdisciplinary</td>
<td>Morrison (2006)</td>
<td>• Interdisciplinary bridging among discrete disciplines treated as an entity.</td>
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<tr>
<td></td>
<td></td>
<td>• Offers students one of the best opportunities to make sense of the world holistically, rather than in bits and pieces.</td>
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<tr>
<td></td>
<td></td>
<td>• Rigorous academic concepts are coupled with real-world lessons.</td>
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<tr>
<td></td>
<td></td>
<td>• Students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise.</td>
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<tr>
<td></td>
<td></td>
<td>• Enables the development of STEM literacy and with it the ability to compete in the new economy</td>
</tr>
<tr>
<td>Interdisciplinary education</td>
<td>Micah et al. (2011)</td>
<td>• Interdisciplinary education that seeks to combine science, technology, engineering, and mathematics in one course</td>
</tr>
<tr>
<td>Integrated approach</td>
<td>Sanders. (2009)</td>
<td>• Approaches that explore teaching and learning</td>
</tr>
</tbody>
</table>
between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects.
In this section, I have discussed some definitions integrated STEM education. The main question in these various views of integrated STEM is why and how implementation be done in the classroom? In the following sections, I will review the literature that explores the features of integrated STEM, its goals, benefits, and the various implementation approaches.

Features of Integrated STEM Curriculum

There might be an overlap between integrated STEM approaches and features of integrated STEM, but some studies have explicitly focused on the characteristics of integrated STEM curriculum and attributes that students should possess. This is the reason why I have separated the two. In this section, I will examine some of these characteristics of the integrated STEM curriculum and student attributes. There are several perspectives on how an effective integrated STEM education program and curriculum should look like. The National Science Foundation, NSF, has funded several projects, which are geared towards developing STEM curricular products. These products have the potential of being applied to the components of STEM education (Lantz, 2009). Lantz (2009) argued that integrated STEM education curriculum should have the following features:

- It should be standards-driven and involve understanding by design (UbD)
- It should involve inquiry-based teaching and learning
- It should include problem based learning (PBL)
- The curriculum should employ performance-based teaching and learning
- It should contain 5E teaching and learning and assessing cycle
- It should also include both formative and summative assessments

Morrison (2006) also argued that integrated STEM curriculum should:

- Promote active learning and student centered
• Promote innovation and invention
• Enable engineering and classroom laboratory to be physically united
• Include computers or laptops with STEM software like CAD, as well supports multiple teaching strategies.

As for students in the integrated STEM education, Morrison (2006) argued that they should possess certain attributes. Morrison (2006) asserted that students who are STEM educated student should be problem solver, innovator, inventor, self-reliant, logical thinker, technically literate, and be able to relate STEM education to the community and the work place. To be STEM educated Diaz and King (2007) argued that the curriculum should be designed in way that it would enable students to have variety as choice of learning tasks, receive explicit explanations about the tasks, have opportunities to model solutions, engaged in student-centered instructional environment and each student should receive individual support. Table 2.2 shows some features of integrated STEM curriculum.
<table>
<thead>
<tr>
<th>Researcher</th>
<th>Features identified</th>
<th></th>
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<tbody>
<tr>
<td>Lantz (2009)</td>
<td>• Be standards-driven, involves understanding by design (UbD)</td>
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<tr>
<td></td>
<td>• Involves inquiry-based teaching and learning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Involves problem based learning (PBL)</td>
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<tr>
<td></td>
<td>• Involves performance based teaching and learning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Involves 5E teaching and learning and assessing cycle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Involves both formative and summative assessments</td>
<td></td>
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<tr>
<td>Morrison (2006, p.5)</td>
<td>• Active and student centered,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Promotes innovation and invention,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Makes sure Engineering and classroom laboratory are physically united</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Posses computers or laptops with STEM software like CAD, and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Supports multiple teaching strategies</td>
<td></td>
</tr>
<tr>
<td>Morrison (2006)</td>
<td>STEM educated student should have the following attributes:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Be a problem solver</td>
<td></td>
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<tr>
<td></td>
<td>• Be an innovator</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Be an inventor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Be self-reliant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Be logical thinker and technically literate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Be able to relate STEM education to the community and the work place.</td>
<td></td>
</tr>
<tr>
<td>Diaz &amp; King (2007)</td>
<td>• Students have variety as choice of learning tasks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Students should receive explicit explanations about the tasks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Students should have opportunities to model solutions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Students should be engaged in student-centered instructional environment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Make sure each student receives individual support</td>
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</table>
Breiner, Johnson, Hackness and Koehler (2012) viewed STEM education as education that is focused on inquiry and project–based activities. The authors argued that teachers have to relate STEM curricula closely to the work of real-life scientists and engineers. For integrated STEM education to be successful, it is vital for those involved to have a common framework that guides them toward various phases of implementation. Though many of the potential features have been articulated, very little implementation in an actual classroom setting has been done as evident in the literature. As a result, I believe that many educators still remain skeptical and critical of the future and success of integrated STEM education because they have not seen enough evidence that support curricular goals.

**Goals of Integrated STEM Education**

According to the Committee on highly successful schools or programs in K-12 STEM education of the National Research Council (NRC, 2011), some goals of K-12 integrated STEM include helping students learn STEM content and practices, developing positive dispositions toward STEM, and also preparing students to be lifelong learners. The report from the Committee further stated that a successful STEM program would raise the number of students who ultimately engage in advanced degrees and careers in STEM fields as well as boost interest and engagement in the STEM-capable workforce, and enhance STEM literacy for all students as well as increase women and minorities’ participation. The President’s Council of Advisors on Science and Technology (PCAST, p.15-17) pinpointed four main goals of STEM education. These goals were to ensure a STEM-capable citizenry, cultivate future STEM experts, build a STEM proficient workforce and close the achievement and participation gap by the number of minority and women who participate in STEM to make full use of the country’s potential. In the study being reported in this dissertation, I am focusing on the United States.
**Integrative STEM approaches.**

Although integrative practices are widely claimed and endorsed, there is little research to guide STEM educators in making thoughtful decisions about what to integrate with what, why, when, how, and for whom (Sandra et al, 1999). Many have focused their writings on personal opinions about integrative learning and teaching, but have very superficial or limited empirical data to support their claim about the knowledge gained from these integrative approaches. The concern in this area is more about the how, what and when of integration, stressing the fundamental role of social interaction, and the role of the community in the process of making meaning and knowledge construction.

In order to better understand the approaches used in STEM integration, I will examine various curriculum integration approaches in the next section. Drake and Burns (2004) presented three different curriculum integrative approaches, multidisciplinary, interdisciplinary, and transdisciplinary. They argued that all three approaches fit on an integration continuum. But as noted above integrated STEM might be a little more than any of these three and that is why the “meta-discipline” has been used to describe it. Drake, Jacobs, Beane and Vars, (1992) explained different interpretations of curriculum integration, referring to the curriculum as interwoven, connected, thematic, interdisciplinary, multidisciplinary, correlated, linked and holistic (Alberta Education, 2007). Curriculum integration is more than a clustering of related learning outcomes. The selection of learning experiences should be based on the extent to which they promote progress or broaden and confirm understanding (Alberta Education, 2007).

Furthermore, Sanders (2009, p.21) provides the definition of integrative approaches in STEM as “approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects”
Zubrowski (2002) further pointed out that integrative approaches require close collaboration among STEM teachers, STEM teachers’ commitment to the integrative approach, and administrative support. Zubrowski (2002) added that challenging and authentic tasks often require integrated instruction, which blends subject matter disciplines into thematic or problem-based pursuits, and instruction that incorporates problem-based learning or project-based learning. Thus integrated instruction is done a way that connects concepts STEM disciplines to the project that students work on. The most effective integrated STEM programs encompass themes with a high potential for student interest, authentic problem solving, and rich, standards-based content in STEM (Satchwell & Loepp, 2002). This is consistent with the claim that the project-based approach to STEM, or “learning by doing,” is grounded in constructivist theory (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005) that is revealed to improve student achievement in higher level cognitive tasks like mathematical problem solving and scientific processes (Satchwell & Loepp, 2002).

Frank, Lavy, and Elata (2003) defined the role of the instructor in a project-based learning implementation as when “… lecturing to passive students is replaced by encouraging motivation, tutoring, providing resources, and helping learners to construct their own knowledge” (p. 280). Thomas (2000) defined the issues about the positive side effects. Vygotsky’ theory of cognitive development with emphasis on social interaction or collaboration is reflected in most of the research that involves integrative approach. It highlights the importance of employing metacognitive strategies within project-based learning environment.

Furthermore, Becker and Park (2011) subdivided integrative efforts in STEM into four categories: integrative efforts in Science, integrative efforts in Technology, integrative efforts in engineering and integrative efforts in mathematics. The basic idea behind this division is the fact
the emphasis would be on a particular field, for example, in integrative effort in technology, the focus is on technology education. However, each of these divisions is integral part of the entire STEM integration.

Based on the approaches in the literature, in the integrated STEM education process, students ask some inquiry-laden questions, brainstorm and refine the answers that they may come up with. In some cases, the teachers are the learners and may likely go through the same process as their students. For example, Felix and Harris (2010) conducted a study on the use of an innovative instructional method in which STEM disciplines were incorporated into a project-based design challenge wherein teachers participated in constructing a passive solar house model. Teachers involved in the project became very interested about some of the science behind alternative energy and in some of the energy projects located in their area. As for what teachers might gain from these integrated projects, Meyrick (2011) stated that:

Educators are eager to reduce performance gaps among particular ethnicities and socio-economically disadvantaged students by refining student skills. Moreover, learning activities are designed to focus on student engagement, knowledge acquisition, literacy analysis, synthesis, and critical thinking skills that will impact the depth of student learning (p.12).

This indicates that if teachers receive the necessary support, then they would possibly implement integrated STEM instruction more effectively in their classroom. In this study, I examined the type of support that teachers received by asking the teachers during the interview. This is because I believe that teachers would properly implement the integrated STEM instruction if they lack the knowledge of the subject matter and even the appropriate implementation approach. As a result implementation has to answer the “what”, “why” and “how” question about the
implementation of integrated STEM instruction.

For some researchers the area of curriculum integration begins at the point of “what is the curriculum” (i.e., the reference point), while for others it is “how” (the processes that support integration). For example, Venville, Wallace, Renne & Malone (2004) focused on the process of learning, decision-making and how students characterized various sources of knowledge in an integrated STEM based project. Venville et al. (2004) study revealed that student approach to working in an integrated STEM project was by bringing knowledge from various disciplines to apply to the project. That was more of compartmentalized knowledge or piecing together (each piece from a different concept) because the knowledge from physics had nothing to do with that from math or computer science. In other words, what students learnt from various disciplines, could still be understood without the project. This implied that the students did not actually understand the connection among the concepts in the project, probably because these connections were not made explicit. This is something that NAE and NRC (2014) emphasized. NAE and NRC (2014) argued that students could not spontaneously make the connections. It is the responsibility of the teacher to make these connections explicit to the students for integrated STEM instruction to achieve its purpose. In my study, I also examined whether students were able to make connections on their own by asking during classroom observations. Venville et al. (2004) based their research decision making processes and sources of knowledge in an integrated teaching and learning setting. Their study was conducted in a Year 9 classroom as students undertook a ten-week solar-powered boat project (they were asked to build a solar boat) and were exposed to related concepts from science, technology and mathematics. The respective teachers taught these concepts. Data collection involved detailed case studies of three pairs of students, interviews, classroom observation and analysis of the artifacts and portfolios produced
by the students during the project. Students were found to access knowledge from a variety of sources, including teacher’s notes from formal instruction, informal interactions with the teacher, observation of and interaction with other students, as well as sources outside the classroom.

Venville et al. (2004) found that the utility of the knowledge sources was influenced by the nature of the task. Students performing open-ended tasks drew on a wider variety of knowledge sources than those participating in less open-ended tasks. Moreover, discipline-based sources often were not as helpful in solving open tasks. Schaffer et al (2012) emphasized the importance of employing metacognitive strategies within project-based learning environment.

Roth (1998) carried out an extensive case study centrally concerned with knowing and learning in communities in which students have significant opportunities to take charge of their own learning. Roth’s central argument, similar to that of O’Loughlin (1994), was that cognition is not something that occurs exclusively in the mind of people, but is something that arises from the interaction of humans with their social and material settings. This is a derivative of Vygotsky’s theory of cognitive development (Vygotsky, 1978). Roth claimed that children’s learning about engineering could be understood as the construction of networks that include various actors, resources and practices in a community. Roth examined the processes by which resources and practices come to be recognized as shared within such a knowledge producing community. He described the circulation of resources, such as facts, artifacts, materials and tools. Through the case study, Roth created an image that cognition arises from an organic whole, rather than from the interaction of separate and independently modeled minds and settings. This is similar to Fogarty’s (1991) concept of blending the disciplines through "overlapping skills, concepts, and attitudes" (p.64). What these tell us about integrated STEM education is that learners could draw knowledge from various areas or “communities” in order to build their
cognitive abilities. Hence, there is no doubt that student experience play a key role in integrated STEM education.

In a similar study about sources of knowledge to student learning, Reiss and Tunnicliffe (1999) examined sources of knowledge with regard to children’s knowledge of plant names. Overall, 94% of the presented plants resulted in students being able to state where they had learned the name in question. As would be expected, the five-year-old children appeared less able to do this (81%) than the fourteen-year olds (98%). The most notable conclusion from this study was the relative infrequency with which TV, video, CD-ROM and books were mentioned as sources of knowledge. The order of importance of sources of knowledge about plants for these children was: home; direct observation; school and TV/video/CD/books. The authors tentatively attributed the findings to the fact that plants are found all around us and noted that from a classroom teacher’s point of view, school has a disappointingly low place in children’s recollected learning about plants. I brought this study up because most of the studies on integrated STEM education require students to construct their own understanding and so it is important to know some potential sources of student ideas. This could help with the selection of an implementation approach and the type of scaffolding. These are areas that I paid attention to in my study wherein I examined the type of scaffolding the teachers employed in their classroom.

**Other Research-based Integrated STEM Approaches**

Furthermore, other approaches involve the process of inquiry-based activities that support students to contextualize the project with respect to prevailing knowledge and experience and communicate what they have learned (Laboy-Rush, 2011). For example, Fortus et al. (2005) conducted a study to find out if the enactment of a Design-Based Science (DBS) unit supported
student efforts to build and transfer problem-solving skills and new science knowledge to the solution of a new real-world design problem in a real-life setting. The participants were one hundred and forty-nine middle grade students who participated in the DBS unit. The student understanding was measured by identical pre-instructional and post-instructional written tests. The results showed a significant increase in the student science content knowledge. Engineering design based projects have also been used for integrative efforts in STEM. For example, Riskowski, Todd, Wee, Dark and Harbor (2009) conducted an engineering design project that was focused on water resources in an 8th grade science class. Students were placed in two groups. One group was exposed to an engineering project (treatment) while the other was on a more traditional format (control). The student knowledge of water resource issues was assessed using pretest and posttest. The researchers found out that the students showed improved content knowledge and higher level of thinking on open-ended questions. These examples are indications that STEM integrative approaches in science education have positive effects on student science learning (Becker & Park, 2011). Also, Venville, Wallace, Rennie and Malone (2000) conducted a study to examine how to describe integrated teaching and learning in science, mathematics, and technology when it was applied in a traditional, discipline-based school environment. They investigated the impact of integrated teaching to student learning. The students designed a solar boat, which was a technology project. The researchers concluded that the project provided a context for the students to apply the understandings they had developed in science, mathematics, and technology. In general, the integrative approaches among STEM subjects in technology education offer students the constructivist learning and teaching context (Becker & Park, 2011).

Most of these approaches are contextually based, hands-on, cooperative group work (Furner & Kumar, 2007; Frykholm & Glasson, 2005; Miller & Davison, 1999; Daniels et al.,
2005) where there is a lot inquiry and discussion in the classroom among students and teachers. Table 2.2 shows some integrated STEM implementation approaches discussed in this section of the chapter.

Based on these approaches, I suggest that integrated STEM approaches should include instruction aimed at developing student ability to communicate using scientific discourse. Educators can enable students to participate in scientific discourse by providing a conducive and respectful environment for learning and carrying out their integrated STEM based projects. Students should feel comfortable working in groups (cooperative learning) and respect each other. Topics for discussion and the projects should be well introduced in order to attract student interest and attention.

**Benefits of Integrated STEM in Classroom Learning**

Though there has been a lot of debate over what integrated learning is (the how and what of integrated learning), there has been a considerable emphasis on the importance and benefits of integrated learning, especially in STEM education. For example, Becker and Park (2011) pointed out that integrative approaches improve student interest and learning in STEM. They did a meta-analysis of twenty-eight studies to examine the effects of the integrative approaches among STEM subjects and concluded that students who participated in these experiences demonstrated greater achievement in STEM subjects. According to NAE and NRC (2014), when STEM is taught in a more connected manner and in real life contexts, the content becomes more relevant to the students and teachers. When subjects are more relevant to students, it could motivate learning, and improve student achievement, interest and determination (NAE & NRC, 2014, p.1).

Wai et al. (2010) found that learning activities in which students practice using integrated skills to solve problems allow for deeper and more meaningful student learning. This implied
that encouraging students to work together to design solutions to problems in a foundational and authentic environment using real-world data and problems would improve student achievement (Meyrick, 2011; Dyer, Reed, & Berry, 2006). Integrated curriculum “provides opportunities for more relevant, less fragmented, and more stimulating experiences for learners” (Furner & Kumar, 2007, p. 186). Cross-disciplinary learning involves an evolution from individual to collaborative thinking by team member (Shaffer et al, 2012). From the literature, it is evident that integrated projects which involve a great deal of collaboration among peers and teachers improve motivation in studying STEM and provide the necessary basis for scientific reasoning, increases student creativity, cooperation, social and transversal skills, and entrepreneurship.

And in keeping with these scholars’ statements, the NGSS emphasized three major dimensions: 1) Scientific and engineering practices; 2) Crosscutting concepts that unify the study of science and engineering through their common application across fields; and 3) Core ideas in four disciplinary areas: physical sciences; life sciences; earth and space sciences; and engineering, technology, and the applications of science. Based on the NAE and NRC (2014) call for integration and the NGSS emphasizes on interdisciplinary instruction, I believe that in order to support student meaningful learning in science and engineering, all three dimensions mentioned above need to be integrated into standards, curriculum, instruction, and assessment. Engineering and technology were included with the natural sciences (physical sciences, life sciences, and earth and space sciences) for two critical reasons: to reflect the importance of understanding the human-built world and to recognize the value of better integrating the teaching and learning of science, engineering, and technology. As noted in this science framework, there is greater emphasis on the importance of integration to learners. The framework has not explicitly defined what it means by integration, but the meaning can be inferred from the
framework’s main objectives. This will lead to varied interpretations at the level of implementation.

The previous examples provide evidence that if integration were properly implemented, it would have lifelong benefits to student learning and their community, as a whole. It has the potential to make connections between curricula and the real world (Fogarty, 1991), to help students to learn (Wolfe, 1990), to provide a conducive learning environment, to encourage higher order and critical thinking, creativity and understanding, and to motivate students to learn (Satchwell & Loepp, 2002). Also, integrated STEM education can help teachers impart skills and knowledge that reverberate with their students in a more meaningful and thought-provoking way (NAE & NRC, 2014). In my view, it could also promote the acquisition of STEM competencies at a young age by influencing what and how students learn. Students have to see meaning in their learning. In line with these claims, Becker and Park (2011) examined twenty-eight studies in their meta-analysis study on the effects of integrative approaches among STEM subjects on student achievement. The effect sizes from thirty-three studies were calculated to examine the effects of the integrative approaches among STEM subjects. The overall effect size from the studies was 0.63. Thus, it was a good idea to put these studies together because it showed the overall impact of integrated STEM education on various student learning outcomes. With respect to the grade levels, the effects of integrative approaches showed the largest effect size of 1.12 at the elementary school level and the smallest effect size of 0.33 at the college level. Therefore, integrative approaches produce more effect in the elementary level than at the college. Regarding the types of integration in STEM, the integration of four subjects presented the largest effect size of 1.76 and E-M (Engineering-Mathematics) and M-S-T (Mathematics-Science-Technology) showed the smallest effect size of 0.03. In addition, the achievement through integrative
approaches in STEM achievement showed the highest effect size of 1.76 and mathematics achievement showed the smallest effect size of 0.26. The results of this meta-analysis revealed that in general, the integrative approaches among STEM subjects have positive effects on the student achievement.

From the student perspective, integrated STEM also shows significant benefits. Laughlin et al. (2007) explored student perceived notion of integration in a first-year, project-based engineering curriculum at an innovative private engineering school. Pilot study data from interviews of seventy-five students, a first-year student cohort was analyzed. Three factors affected student perceived level of integration: (1) the connections made by students among mathematics, physics, and engineering design classes; (2) the student perceived level of communication, cooperation, and synergy between faculty teaching the above three classes; and (3) the level of perceived faculty involvement in student learning experiences. A positive relationship was found between the extent to which students perceived integration and the extent to which integration contributed to a positive learning experience. The authors’ early findings also indicated that integration in engineering education, if implemented with care, would prove to be an effective method to increase the retention of students in undergraduate engineering education.

In this section, I discussed some of the implementation approaches that have been used in integrated STEM education. These implementation approaches have been shown to have wide-ranging effects on student learning. The approaches that I presented in this section include both those that are based on theory and those based on empirical studies. I will then discuss some challenges that have hindered the effective implementation of integrated STEM education.
Challenges or Barriers in Integrated STEM Instruction

Some researchers and educators have inadequately understood learning in an integrated context (Venville, Rennie & Wallace, 2004) and as such have either not implemented or have not understood its acclaimed benefits. According to Bybee (2010), the first challenge of creating an integrated context for science and science related instruction involves actively incorporating technology and engineering in school programs. It is not an easy task to design integrated curriculum or projects that will better achieve the intended goals in STEM classrooms. Twenty years ago Pearson (1994) remarked that "As we begin this journey into curricular integration, be prepared to enter a messy, complicated world -- a world filled with fuzzy ideas rather than clear, crisp concepts, complexity rather than simplicity, and hedges rather than prescriptions" (p. 14). And it is important to note that we have not made that much progress in this journey that Pearson talked about. To me, most of the challenges faced by science teachers are due in part to the absence of shared or common definition of integrated learning or lack of proper conceptualization of integrated STEM instruction and thus lack of ways to infuse integrated STEM instruction into the science curriculum and instruction. NAE and NRC, (2014) argued that:

Despite the rise in interest in providing students with learning experiences that foster connection making across the STEM disciplines, there is little research on how best to do so or on what factors make integration more likely to increase student learning, interest, retention, achievement, or other valued outcomes. (p.2)

There are also numerous barriers in schools that hinder the proper/ effective implementation of integrated STEM approach to teaching and learning (Bergstrom, 1998; Grossman & Stodolsky, 1995; Lounsbury, 1996; McCarthy, 1988). Cantu, Roberts and Strimel (2013) carried out a study
to determine practiced approaches to addressing common challenges teachers faced integrated K-12 STEM education curricula. They sampled 914 teachers; only 48% of the teachers said they had high confidence regarding content knowledge of integrated STEM content, 40% had a high confidence level regarding their ability to teach an integrated STEM lesson, 48% believed they had the ability to guide student-led instruction. In the same study only 50% believed they had the ability to acquire and maintain student engagement throughout an integrated STEM lesson and 46% believed they have the ability to provide varied instructional strategies when teaching integrated STEM lessons.

Cantu et al. (2013) also found that being able to effectively instruct content knowledge from each of the STEM disciplines was one of their biggest challenges. Other challenges identified by these teachers were the lack of training in instructional strategies for integrated instruction from their teacher preparation program, lack of student abilities in STEM, lack of ongoing teacher support, limited access to resources like materials and funding.

How do you overcome these challenges? This is the question that has to be answered in order to move integrated STEM forward and increase active teacher involvement. Cantu et al. (2013) asked teachers what they believed was the most effective means to address these challenges. Twenty-eight percent of the teachers believed that modifying instruction was one of the most effective means that can be used to address these challenges. Eighteen percent believed research participation would alleviate the challenges. Other approaches identified in Cantu et al (2013) were: professional development changes, teacher preparation changes, and STEM real life application.

Common challenges that hinder the successful implementation of integrated STEM education include additional preparation time for teachers, availability of the necessary materials
and resources, lack of support and collaboration, and getting teachers to change their attitude toward that of embracing integrated STEM education (Laboy Rush, 2012). Teachers might have to learn additional content and how to use new materials, which might be difficult. (Laboy-Rush, 2012). Some proposals to mitigate these challenges include support from the administration, staff development, bringing in consultants to help teachers learn the new approach (Satchwell et al., 2002) and motivating teachers and helping teachers learn the student materials (Diaz et al., 2007).

One fundamental aspect of effective integrated STEM education is overcoming the above-mentioned challenges or barriers. My study provides another context to integrated STEM education implementation. One of its goals is to explore the challenges or barriers that hinder its proper implementation and propose ways to alleviate them. It is essential to incorporate the student and teachers’ perspectives in order to propose suitable solutions to these challenges. It is important to address teachers’ attitude toward this shift in teaching practice. This is not an easy task to handle, but it would be helpful to understand the teachers’ perspectives toward this type of teaching approach (integrated STEM instruction). Therefore, in the study, I also seek teachers’ perspectives on the barriers to integrated STEM implementation.

**Summary**

Thus far I have discussed research on the educational values of robotics in the classroom. Then, I have also reviewed the various definitions of STEM education, most importantly the differentiated STEM, STEM education and integrated STEM education and hence a working definition of integrated STEM education through a review and analysis of the literature. A variety of the integrated STEM curriculum implementation approaches have been discussed. The goals, and benefits of integrated STEM education in the classroom have been examined. The
features of integrated STEM curriculum have also been discussed. In the next chapter, I will discuss the methodology employed for this study. I will also present my epistemological and ontological stance. I also examined the challenges or barriers that teachers faced with integrated STEM instruction. Finally, I have presented how some exploratory research in science education has been carried out.
CHAPTER 3

METHODOLOGY

The methodology of a study is a detailed plan of action, and includes the design and process that guides the selected method (Crotty, 2003). In order to answer the research questions involved in this study, a plan of action was designed. Methodology of the research and the interpretations of results are guided by the belief system of the researcher (Lave and Kvale, 1995), which is in turn informed by the ontological, epistemological and methodological assumptions of the researcher (Guba & Lincoln, 1994). It is therefore important to make these assumptions explicit so that they guide people’s understanding of what my research has to offer (Crotty, 1998). This chapter provides a detailed description of the methodology used in this research study. In the chapter is focused on my epistemological and ontological stance, research design used, the methods, which includes the data collection and analysis techniques, research design, and trustworthiness.

My Epistemological And Ontological Stance

I begin this chapter by clarifying my epistemological and ontological standpoint concerning student construction of meaningful and relevant knowledge, and how teachers can assist in building student meaningful knowledge. According to Crotty (1998), epistemological standpoint is “a way of understanding and explaining how we know what we know” (p.3) and ontological standpoint is “a way of understanding of what is” (p.10). In constructivism, individuals base their personal experiences with their environment to construct knowledge. The environment includes the person’s social interactions in their daily lives. These interactions help
build their understanding of knowledge, which in turn leads to the formation of an individual’s own philosophy of knowledge. Therefore, interactions with others play a key role in knowledge construction. For example, individuals working in a group could each be influenced by the views of the other group members, which can result in a common or shared understanding of meaning (Gredler, 1997). This underscores the fact that knowledge construction is somehow mediated as a result of social interaction, which build on one’s experiences. As a result it would be more helpful if new knowledge were linked to the knowledge already known by the individual and which can form a framework onto which to attach new knowledge. In this way, the individual who is learning this new knowledge is able to connect it to what was previously learned. My epistemological and ontological stances lean more towards social constructivism and constructionism. Using a framework like constructivism, which shapes the orientation of the researcher, can help them to understand why the knower knows what they know by studying an artifact, like a robot, that a student has built to perform a certain task (Papert & Harel, 1991). The robot, which is an artifact, could be viewed as a representation of the kind of knowledge the student has developed about the task and how the student applied their previous knowledge. To me, an activity such as the robotics activity could provide students with the opportunities to not only apply their understanding of science concepts and other STEM concepts but also help them clarify their understanding of certain concepts. This application could lead to a change in previously held knowledge of a concept and a better conceptual understanding among students. I also believe that conceptual understanding could be influenced by student everyday experiences. Venville, Rennie and Wallace (2004) argued that students applied knowledge from various sources in their integrated STEM based project. Hence, any attempts toward enhancing conceptual understanding have to be related to these experiences. From my own teaching
experience in the middle science, making facts more relevant and concrete rather than abstract could be a better way of enforcing and enhancing conceptual understanding. While I agree that there is autonomous knowledge development (Gardner & Miller, 1999), Although, I am a constructivist, I also consider that students cannot be left to make the judgment on what counts as knowledge on their own, but rather need to be guided in their journey of knowledge discovery and development. This guidance could take different forms depending on the teacher’s unique pedagogical view. To me as a science educator, it would be helpful to make activities that are hands-on and connected to real life situations. If students are autonomous learners who are left to determine when they think they have made sufficient knowledge gains, then it could pose the problem of where sufficiency should end. This implies the guidance that is provided to students has to include information about what constitutes sufficiency. This does not rescind the fact that students could be considered autonomous learners but should be guided to come up with their own knowledge within certain standards. Providing guidance and some standards will help students not just formulate their interpretations of the physical world, but also justify those interpretations.

Epistemological stance also portrays the manner in which I, as a researcher, perceive the world. It involves how I think knowledge is created and shared and how I believe truth is defined. I view truth as a function of an active process of engagement with the society, which is in agreement with the pragmatic theory of truth found in the work of Charles Peirce, William James and John Dewey (Johnson & Onwuegbuzie, 2004). By active engagement I mean that a person lives and participates in a community and that community has its own culture that influences individual’s beliefs. This has led me to assert that truth depends on what the society generally accept to be true. My view of truth is thus informed by Williams James
characterization of truth in terms of usefulness and acceptance (James, 1907). In addition, I am also of the opinion that truth does not occur independently of the world but rather truth is contextual. For example, what is considered true in country A might not be necessarily true in country B. There might be universal truth, like saying the earth exists, but when it comes to the “how” and the “what” of the stated facts, then other factors like cultural beliefs, individual experiences and beliefs play a key role. Truth therefore becomes non-static in nature and can always be changed as long as human interaction and experiences change. In terms of science education, there is context in which knowledge is used should be taken into consideration and multiple viewpoints should be seen as alternative conceptions rather than right and wrong (Hewson, 1992).

Crotty’s (1998) description of ontology as “a way of understanding of what is” (p.10) means that reality exists but that we need to find ways to know it. If this is true then it means we do not need knowledge construction but instead, need approaches to get to the reality. There are certain realities like the existence of the world. However, knowing the reality is very subjective as it is influenced by our experiences with our environment as mentioned earlier. It is therefore important that we make an effort to relate any reality to a learner’s experiences so that it becomes more meaningful and relevant. Particularly in STEM education, new concepts have to be made concrete and not abstract or proceed cautiously from concrete to abstract, giving the learner the opportunity to be opened to different opinions and ways of thinking.

Research Design

In order to better understand how middle school science teachers integrated technology objectives with science objectives, I conducted an exploratory qualitative study of the development and implementation of integrated STEM instruction in the middle school
classroom. The study involved the integration of technology and science objectives by utilizing robotics kit to design robots that could perform a particular task assigned by middle school science teachers. The study took place in a middle school in Southeastern United States. Five teachers were involved in this study as participants and two middle school classes (sixth and eighth grade). Sixth and eighth grade students were also participants in this study. An exploratory qualitative study approach was used for this integrated STEM education research because this area has very limited exploration or substantial research done (Bogdan & Biklen, 2007).

This chapter constitutes a comprehensive description of the research methodology that was used in the study and is structured into several sections that specify a framework within which to describe the research plan.

The research questions that this study attempted to answer are:

1. How do Science and Technology teachers restructure the middle school science curriculum and instruction in order to incorporate /implement objectives into science classroom activities using a teaching approach emphasizing robotics equipment?

2. What are the teachers’ and student perceptions of the STEM implementation in regular science classroom?

3. What theoretical relationships are discerned by the analysis of data that are gathered?

This study was an exploratory qualitative study because of the limited number of studies in this area so far. According to Labaree (2013), an exploratory design is conducted if the research problem has a small number of or no previous studies to refer to. Exploratory design is aimed at gaining a better understanding and acquaintance with the problem in order to enhance further research. With this definition from Labaree (2013), I believed after perusing the literature on
integrated STEM education that there wasn’t much empirical research in this area. Labaree (2013) stated the following rationale behind exploratory design:

- Familiarity with basic details, settings and concerns.
- Well-grounded picture of the situation being developed.
- Generation of new ideas and assumption, development of tentative theories or hypotheses.
- Determination about whether a study is feasible in the future.
- Issues get refined for more systematic investigation and formulation of new research questions.
- Direction for future research and techniques get developed.

I therefore grounded the research methodology of this study in the exploratory qualitative research and partial design based research framework. This method was suited for this study because the study took place in an applied context (the middle school science classroom) (Cotton et al., 2009). When Brown (1992) introduced design experiments as a methodology, she defined its purpose as “to engineer innovative educational environments and simultaneously conduct experimental studies of these innovations” (p. 141). According to Brown (1992), there are several independent aspects that characterize the classroom settings. These independent aspects like curriculum selection, testing, training must be considered as a whole operating system (Krange et al., 2008). This means that in using this methodology, the context of study must be taking into consideration, even though it might not be included as part of the units of analysis (Krange et al., 2008).
The technology implemented was new to the middle school science students and teachers. The teachers started off without a clear understanding, goal or approach of how to integrate these technology objectives with their science objectives into their classroom, but were determined to implement it anyway. This implied that there would be an iterative and continual testing and refinement process, details and evidence of which needed to be captured and analyzed.

**Research Site**

This study was conducted in a middle school in the Southeastern United States. According to the school website, the school is an independent, co-ed day school. It offers classes from 3-year-olds through twelfth grade. It has nine hundred and fifty-seven students from 19 countries and 18% minority enrollment. It offers after school programs like robotics and has a dedicated and highly qualified faculty. The research focused on the middle schools grades fifth through eighth and in particular the interface of science instruction with robotics in those grades.

I chose this particular school because it has a robotics program, which has been operating as a club in the school and the students have participated in many robotics tournaments like the FIRST LEGO tournaments. In addition, the school administration decided, as a means to make an initial step in an implementation of the STEM curricular movement, to extend the robotics activity into the mainstream classroom. However, the science teachers and the technology teacher had to find the most appropriate instructional approach in order to successfully implement it in the middle school classroom. Their goal was to give students a STEM experience to get a feel for what experts in the field of STEM actually do.

Prior to the study, I had attended some of the club sessions and observed students (both middle and high school) work on their robotics with a lot of passion and determination to
succeed (win a tournament). This gave me the opportunity to become familiar with robotics and to meet most of the teachers.

**Instructional Context**

According to an article written by the School Director of Academic Affairs and published in the school magazine, the school’s board of trustees decided to develop a long-range plan for the school in 2011 and one of the “Centers of Emphasis” was to enhance Science, Technology, Engineering and Mathematics (STEM) curriculum. This school has maintained a long tradition of integrating technology as a tool for instruction and learning (School magazine, 2014). For example, the school has participated in robotics competition since 2002. Thereafter it continued to field at least one team each year in the First Lego League (FLL) and the popularity of the program has continued to grow in the school.

According to the FLL website, it is a robotics program designed for 9 to 14 years old. Its goal is to get students excited about science and technology and for them to acquire some valuable employment and life skills. FLL is not designed solely for classroom use. The website provides some robotics activities that could be purchased and used in the classroom, but these activities are not related to any science curriculum.

The robotics program has existed in the school for over 15 years, but until recently only existed as an after-school activity. During each class period, student’s design, reflect, research and rebuild their robots. These robots are built to perform a particular task, like navigating through the course of an obstacle, and other challenges, which are based on annual themes provided by the FLL.

As students participated and continue to participate in this robotics program and tournaments, the school community has noticed that many students are interested in the program.
Those who participate are developing skills like problem solving, creativity, research, collaboration and hands-on learning. The administration decided to not limit it as an after school or extracurricular activity, but to find ways to integrate these robotics activities into the traditional classroom to support specific areas of the curriculum. They decided to get the middle science teachers together with the technology teacher to implement this in the middle school science classrooms.

Participants

Participants in this study included a technology teacher, four middle school science teachers and middle school science students (eighth and sixth grades). The participating teachers in this study were Doris, Shelly, Mitch, Steve and Mario (all were given pseudonyms for confidentiality). Doris has been teaching for over 20 years, Shelly for about ten, Mitch was in his second year and Mario was the technology teacher and had over ten years experience in teaching. The teachers selected for this study are those who implemented the robotics project in their classroom; they were fifth, sixth, seventh and eighth grade science teachers. However, I did not observe the fifth and seventh grades classroom. I partially observed the sixth grade (partially because not all sessions were observed because of administrative procedures that delayed the IRB approval). The classes that were involved in the study are in the sixth and eighth grades. The researcher observed two out of seven class periods in sixth grade and observed 20 class periods in eighth grade. Eighth grade students were interviewed during the observation as they worked on their robotics projects.

Recruitment of the teachers was done through a face-to-face contact. I had already known these teachers before the study and so it was easy to contact them and they were all willing to participate. The seventy-two eighth graders were involved in the project were observed but only
sixteen students were randomly selected to participate in any interview, while the researcher observed and informally talked to all the students. The students worked mostly in pairs with a few groups of three. In the following section of methods I will discuss the research methods. The methods encompass the data collection

**Methods**

**Data Collection**

Data for this study was collected from transcripts from teacher interview, student interviews, and researcher’s classroom observation notes. I employed the participant observation and interviewing techniques to collect data (Glesne & Peshkin, 1992). I designed an observational protocol (See Appendix A) and the interview questions based on the research questions and the literature review in the area of integrated STEM education implementation. In designing the observation protocol, I focused on actions and words taken and used by the students and teachers while working on their integrated STEM project in the classroom. Table 3.0 is a data matrix that shows how the data collected related to each research question in the study and table 3.1 provides more details about the research questions for the reader to better understand what was done.

In the beginning of the first lesson, the teacher introduced me to the students. He informed them that I was there to do research about the teaching of technology and science objectives using robotics and would be asking some questions as they worked on their projects. By the second day of the project, the students were already familiar with me. This helped because they became more comfortable working with me standing by and watching. My role was a participant observer. The students were also comfortable talking to me while working on their
project. The eighth grade had eighty students divided into four groups. Each team consisted of two or three students who were placed into the team by the teacher. There were eight teams in each group. Thus, each day had four sessions and I attended all the sessions for two weeks. I randomly selected from each group two teams and audio recorded their group interactions. I informed the selected teams that I was going to leave an audio recorder at their table so that I could capture their communications.
Table 3.0

Data Matrix

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Teachers’ Semi Structured interview as a source of data</th>
<th>Direct observation field notes as a source of data</th>
<th>Student interviews as a source of data</th>
</tr>
</thead>
</table>
| How do Science and Technology teachers restructure the middle school science curriculum and instruction in order to incorporate /implement technology objectives into science classroom activities using a teaching approach emphasizing robotics equipment? | Yes  
Interview questions:  
Have you used integrated STEM projects in your class before?  
Did you receive any training prior to implementing this project?  
How did you figure the way to implement this integrated STEM instruction in your classroom?  
Did you have to restructure your science curriculum to fit in this new project?  
Was there any collaboration with your colleagues during the implementation process?  
What are some of the changes you made in the implementation process and why?  
How did you incorporate the robotics objectives with science objectives in your science classroom?  
What challenges did you encounter and did you resolve them?  
Did you assess this project?  
Why or why not? If yes, what assessment techniques did you use? | Yes | No |
| What are the teachers’ and student perceptions of the STEM technology            | Yes  
What impact do you think this technology have on your educational practice or on how | Yes | Yes  
Is there anything about how this activity motivates or interests |
<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>What theoretical relationships are discerned by the analysis of data that are gathered?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>What concepts and skills did your students learn from this project?</td>
<td>You taught? Will you use more integrated STEM approaches in your future classroom instruction? If so, how do you intend to incorporate that into your science curriculum or standards?</td>
<td>What is your level of interest and how do you think it came to be that way? Is there something different about acquiring knowledge this way? What have you learned and how have you learned it? Is there any different about what you did in order to learn the science?</td>
<td></td>
</tr>
<tr>
<td>Research Questions</td>
<td>What the researcher needed to know</td>
<td>Possible data source</td>
<td>Main interview questions</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------------</td>
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<td>--------------------------</td>
</tr>
<tr>
<td>How do Science and Technology teachers restructure the middle school science curriculum and instruction in order to incorporate and implement technology objectives into science classroom activities using a teaching approach emphasizing robotics equipment?</td>
<td>Here, I wanted to find out how they introduce the integrated STEM instruction into their existing science curriculum. The instructional approach they used; the types of scaffolds, and assessments used.</td>
<td>Classroom observation notes and Teachers’ interview transcripts</td>
<td>How did you figure how to incorporate this technology into your science curriculum? What are the changes that you made in the process when you started this implementation?</td>
</tr>
<tr>
<td>What are the teachers’ and student perceptions of the STEM technology implementation in regular science classroom?</td>
<td>I was focused on finding out if the implementation of this new technology benefit or does not benefit the following: Instruction in that course, Student learning, as perceived by the teachers and the students Student motivation.</td>
<td>Classroom observation notes, student interview transcripts and teachers’ interview transcripts.</td>
<td>Teachers: What impact did this integrated STEM instruction have on your educational practice and how you taught? What concept and skills do you think your students learned from this implementation? Students: Is there anything that motivates or interests you in this project? What is your level of interest and how do you think it came to be that way? Is there something new about acquiring knowledge this</td>
</tr>
<tr>
<td>What theoretical relationships are discerned by the analysis of data that are gathered?</td>
<td>Here, I am focusing on using the information gathered from the practical implementation of this new technology to illuminate the theory on technology integration in STEM in order to develop a pedagogical model of technology integration in STEM education</td>
<td>Classroom observations notes, students and teachers’ interview transcripts.</td>
<td>way?</td>
</tr>
</tbody>
</table>
In-depth Interviews

The researcher used in-depth interviews in order to better understand the lived experience of the teachers and students during the implementation of the integrated STEM project. As Seidman (2006) contended, “At the root of an in-depth interview is an interest in understanding the lived experience of other people and the meaning they make of that experience” (p. 9). Specifically, the researcher used semi-structured interviews with pre-established questions, but employed probes and some follow-up questions during the interview to obtain more detailed information and clarification of responses from the participants (both teachers and students). Kolb (2012) remarked that interviewing enables the researcher “to gain the perspectives of the individual” (p.84). In the same line of thought, Glesne & Peshkin (1992) asserted that, “the opportunity to learn about what you cannot see and to explore alternative explanations of what you do see is the special strength of interviewing in qualitative inquiry” (p. 65). In addition, it could help confirm some of the things that the researcher observed. It is therefore important to combine research observations with interviewing. This is the reason why I did the observations in conjunction with interviewing in the eighth grade. I have included the interview questions for both teachers and students in Appendix A. The transcripts for the interviews show the follow-up questions and probes that I used during the interviewing process.

During the teacher interview, I asked questions that focused on understanding the instructional approach, especially the implementation approach they used in the robotics projects. I also asked about teacher’s perspective on the impact of integrated STEM instruction on their present and in their subsequent teaching practice. I conducted the teacher interview after each teacher participant implemented the project in his/her classroom. Each teacher’s interview lasted for about half an hour. In order to better capture the implementation process, I
structured the interview questions to focus on any possible preparation and training before the implementation, collaboration with other teachers, and the actual implementation (student arrangement, lesson objectives, teacher’s role, how the activity was related to the curriculum and student assessment). It was important to find out the teachers’ thoughts on the impact of the instruction on student achievement.

Student interviews were conducted during the class time within which the robotics project was being completed. This was due to the fact that the school schedule did not leave students with any free time that the researcher could use to conduct interviews. As a result of this time constraint, the researcher conducted the interviews when the students were working on their projects. It was planned in such a way that it did not interrupt their work. This was done by asking very few questions and by choosing a time that the students were not very busy with their project. For example, when the researcher realized that the students have completed a major aspect of their project, he went to the students and requested a few minutes of their time for an interview. Each interview was conducted per team, not per student. So if there were two students in a team then both were interviewed at the same time. Each interview lasted for about ten minutes.

Prior to the interviews, the researchers met with the eighth grade teacher to discuss the plan for data collection, specifically to find out if asking questions would be an inconvenience during the lesson. The researcher designed student questions and determined at what point in the implementation was the most appropriate time to ask student questions. These student interview questions focused on their perspectives on integrated STEM education. Table 3.2 shows the student interview questions.
Table 3.2

Breakdown of student interview questions

<table>
<thead>
<tr>
<th>Perspective component</th>
<th>Interview questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>What have you learned and how have you learned it? Is there something different about acquiring knowledge this way?</td>
</tr>
<tr>
<td>Action</td>
<td>Was there anything different about what you did in order to learn the science?</td>
</tr>
<tr>
<td>Affect</td>
<td>Is there anything different about how this activity motivates or interests you? What is your level of interest and how do you think it came to be that way?</td>
</tr>
</tbody>
</table>
Direct Classroom Observation Field Notes.

According to Bogdan and Biklen (2007), observation notes help provide an account of what the researcher actually saw, experienced, thought and heard during the observation. These notes helped the researcher to keep track of how the teacher interacted with their students, how the classroom was arranged (students arranged in pairs or groups), and the role of the teacher in the class during the implementation and the student interactions with the teacher. Immediately after each observation, the researcher also wrote extended field notes so that important facts were not forgotten. Field notes provide a comprehensive description of what happened during the observation (Esterberg, 2002, p. 74). These extended notes also helped the researcher keep track of certain details, which could easily be forgotten with time.

The purpose of the classroom observations was to understand the research setting and participants, specifically how the science teachers implemented the integrated STEM project, how these kind of projects motivated students to engage in STEM practices, challenges that the teacher and the students faced during the implementation, the teacher’s role and the general atmosphere in the classroom. Observation of these things would provide a better understanding of how teachers translated their knowledge into classroom practices, student-student interactions, student-teacher interactions and the levels of engagement of the students. Teachers’ actions are an effective way of representing what they know and believe than relying solely on their self-report measures (Van Driel et al., 2001). Some practices are more easily discerned from observations of classroom performances than from what is articulated (Park, 2005). The observation protocol is shown in Appendices B. Each classroom observation lasted the entire class period. Significant events that were likely to have an impact on the student persistence and motivation in the project included the support that the students received, the challenges or
problems they faced, the collaboration among students. These issues were based on student expressions, which were captured during classroom observations and placed into different categories. The categories were support category, challenges and problems category, and collaboration category (Hongisto et al., 2010). For example, if the researcher heard the teacher says to a student “good job”, then that was noted as an expression for the “encouragement and ideas category”. If students were discussing with a fellow student on how to redesign a particular part of their robot, then that was noted under the collaboration category. The observation protocol is shown in Appendix B.

Five groups of eighth grade student discussion were audio recorded during the project across all class periods for the duration of the integrated STEM instruction. The goal was to capture a greater detail of the kind of vocabulary they were using, specifically if they were using concepts from the various STEM disciplines, the role each student was played. The group discussion was audio recorded, then transcribed and coded for themes.

**Logistics, Timeline and Procedures Related to Data Collection**

Data was collected in May and June of 2014. The overall procedures of the data collection including the names and description of various phases are shown in table 3.3.
Table 3.3: Phases of the Study

<table>
<thead>
<tr>
<th>Phase number</th>
<th>Phase Title</th>
<th>Description of Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Pre-Field Work</td>
<td>1. Participant selection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. IRB approval</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Design of interview questions and classroom observation protocol</td>
</tr>
<tr>
<td>II</td>
<td>Data Collection</td>
<td>1. Interview of teachers who had already implemented the integrated STEM instruction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Classroom observations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Interviews (of students during the lessons)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Transcription of audio tapes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Preliminary analysis of data occurred during coding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Member checking and construction of data</td>
</tr>
<tr>
<td>III</td>
<td>Analysis and Interpretation</td>
<td>1. Inductive analysis of data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Interpretive analysis</td>
</tr>
<tr>
<td>IV</td>
<td>Writing It Up</td>
<td>1. Formal dissertation format</td>
</tr>
</tbody>
</table>
**Logistics**

Starting in April 2014, I emailed four Alpha Academy middle school science teachers whom I had met several months ago in a training workshop. I then scheduled interviews with two of the teachers who had already implemented the integrated STEM instruction in their classrooms. I also made arrangements with the other two teachers to observe their classrooms.

In May 2014, after the IRB approval, I began to establish observation dates and conduct interviews. Data collection continued until June 2014. Transcription of the interviews and the writing out of extended field notes took place in June 2014.

From June 2014 through July 2014, I performed a comprehensive analysis of interview transcripts, and field notes. I then assigned themes to the research questions. From August 2014 through January 2015, I engaged in interpretive analysis, this is when I analyzed the data in light of the literature and theoretical framework.

**Timeline**

Table 3.4 shows a timeline that provides an outline of the logistics that were described.
<table>
<thead>
<tr>
<th>Date (s)</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 2014</td>
<td>I contacted Potential participants</td>
</tr>
<tr>
<td>May 2014</td>
<td>I established interview and observation dates with the teacher participants</td>
</tr>
<tr>
<td>May 2014</td>
<td>I began data collection</td>
</tr>
<tr>
<td>June 2014</td>
<td>Data collection ended</td>
</tr>
<tr>
<td>June 2014-July 2014</td>
<td>All interviews were transcribed. Extended field notes were also written. Coding began and preliminary data analysis occurred during coding.</td>
</tr>
<tr>
<td>July 2014-August 2014</td>
<td>Comprehensive analysis of interview transcripts and extended field notes; themes assigned to research questions</td>
</tr>
<tr>
<td>August 2014-January 2015</td>
<td>Interpretive analysis of data</td>
</tr>
</tbody>
</table>
**Data Analysis**

Data collected from multiple sources (students and teacher interview and classroom observations) were analyzed using the inductive approach. The specific form of the analysis used was the constant comparative method (Glaser & Strauss, 1967). According to Hollister (2009), “the inductive approach is a systematic procedure for analyzing qualitative data where the analysis is guided by specific objectives” (p.62). The main rationale of this approach is to let research findings become apparent from the major themes or significant themes inbuilt in the data without any restraints that may occur because of structured methodologies (Thomas, 2003, p.2). Thomas (2003) outlined some of the rationale underlying the design of the general inductive approach. These include: reducing extensive text data into a summarized format, linking the research objectives to the summarized format and coming up with a theory that explains the underlying processes present in the raw data (p. 2). The constant comparative method helps to produce precise themes from the data, which can help provide a better understanding of the data (Grove, 1998). All of these themes and their interconnections could lead to the generation a new theory from the data.

I developed themes from the data by coding and analyzing the data simultaneously (Taylor & Bogdan, 1998). According to Glaser & Strauss (1967), this method was first established for the use in grounded theory methodology, and is now used more widely as a method of data analysis in qualitative research. It needs the researcher to take a single piece of data (e.g. an interview transcript,) and compare it to all other parts of data that are either similar or different. During this process, the researcher starts to examine what makes this piece of data similar and/or different to other pieces of data. The purpose of the constant comparative method is to generate explicit categories that can be useful to better understand the data (Grove, 1998). The
constant comparative method as a form of inductive analysis is focused on generating categories and themes by identifying patterns or regularities from the data without any pre-determined system of codes or categories. According to Taylor & Bogdan (1998):

“Constant comparative approach assures that all the data are systematically compared to all other data in the data set. This ensures that all the data produced is analyzed not disregarded on thematic grounds.”

I developed themes of students and teachers’ perspectives and the way teachers implemented the project from the data by comparing new data to previously collected data (Charmaz, 2000; Glasser & Strauss, 1967). In order to develop these themes, I used the recommendations from Glaser & Strauss (1967) and Charmaz (2000). According to Glasser & Strauss (1967), constant comparative methodology includes four stages “(1) comparing incidents applicable to each category, (2) integrating categories and their properties, (3) delimiting the theory, and (4) writing the theory” p. 105). Charmaz (2000) further proposed some points of comparisons that might be taken into consideration when developing themes from data. These include comparing (a) different people (especially their actions, experiences, situations, accounts, viewpoints (b) data from the same individuals with themselves at different points in time, (c) incident with incident, (d) data with category, and (e) a category with other categories (Charmaz, 2000, p. 515). I used these recommendations to compare student group interactions, and compare categories and themes from teachers’ and student interview transcripts.

Following this method, I analyzed the data in different stages. The first stage involved coding the data set and then comparing these codes so as to eliminate repetitive ones. I coded the classroom observations notes and student and teachers’ interview transcripts using a process of “open coding” (Strauss & Corbin, 1990). Open coding is "the process of breaking down,
examining, comparing, conceptualizing, and categorizing data" (Strauss & Corbin, 1990, p. 61) followed by axial coding. Strauss and Corbin (1990) defined axial coding as "a set of procedures whereby data are put back together in new ways after open coding, by making connections between categories. This is done by utilizing a coding paradigm involving conditions, context, action/interactional strategies and consequences" (p. 96). Selective coding, which is "the process of selecting the core category, systematically relating it to other categories, validating those relationships, and filling in categories that need further refinement and development" (Strauss & Corbin, 1990, p. 116). Selective coding was used as a final coding step in this data analysis.

Charmaz (1999) argued that coding is a kind of shorthand that refines events and meanings without losing any of its vital components. This process helped reduce data to “units of analysis” (LeCompte, 2000). Units of analysis refer to the “the smallest piece of information about something that can stand by itself” (Lincoln & Guba, 1985, p. 345). I started systematically by looking at the first two interviews making a simple list of the similarities and differences between them, and then continuing to the third interview, working my way through all of them. I addressed the question: does everyone express the same/similar opinion or the experience? If yes, it counted as a similarity or if a majority of the respondents expressed a particular view, then it was viewed as a consensus between the respondents.

Also, in the coding process, I employed Bryman’s (2008) suggestions by first reading the transcript as a whole, making notes of major themes and unusual issues, labeling codes, highlighting key words, and finally reviewing the themes, and relationships among themes. I then organized these patterns and relationships into categories and subcategories by looking for similarities and differences in their properties and dimensions (Glasser & Strauss, 1967). Here, “properties are the general or specific characteristics or attributes of a category, and dimensions
represent the location of a property along a continuum or range” (Strauss & Corbin, 1990, p. 117). Coding and category generation occurred simultaneously because there were instances where I had to reread a text and refine the code and the category. This falls in line with Taylor and Bogdan’s (1984) contention that: “in the constant comparative method the researcher simultaneously codes and analyses data in order to develop concepts; by continually comparing specific incidents in the data, the researcher refines these concepts, identifies their properties, explores their relationships to one another, and integrates them into a coherent explanatory model” (p.126).

Following the generation of these categories, a network was developed. A network means “a map of the selected [categories and subcategories] which shows how they relate to one another” (Bliss, Monk, & Ogborn, 1983, p. 8). For example, the network of barriers that teachers faced was created and an attempt was made to see if there was any relationship between them. For example if the barrier of lack of training was related to the barrier of insufficient time for implementation, then it implied that training could be related to time management. This means grouping and eliminating repetition and similar codes and identifying the significance of these codes helped to integrate the categories. I further interconnected these codes by related them to the research questions. Analysis constituted an iterative process of considering and comparing the statements gathered. During analysis, I constantly asked reflective questions adapted from Bowden (1994) such as “What does this statement tell me about the way that integrated STEM was perceived?”

Trustworthiness

According to Lincoln and Guba (1986), there are four alternative sets of criteria to judge the quality of qualitative research: credibility, transferability, dependability and conformability.
“Credibility could be achieved by prolonged engagement with the participants, persistent observation, member-checks, and triangulation of different sources (interviews, observation, documents and research diaries and data coming out of these sources)” (p. 127). Furthermore, Lincoln and Guba (1986) proposed the following criteria for judging the trustworthiness of a qualitative research: “Credibility as an equivalent to internal validity, transferability as an equivalent to external validity, dependability as an equivalent to reliability, and conformability as an equivalent to objectivity” (p. 76). Using these criteria, I ensured the “trustworthiness” of the research through member check, triangulation and prolonged engagement with students. I sent interview transcripts to the teachers to go through and confirm that they represented what they said. In order to ensure credibility, I sent the interview transcripts to the teacher participants for member-check for accuracy and believability (Patton, 2002). Also, I used triangulation to compare the information obtained. For example, there were instances where I had to verify what the teacher said with the observation that I made and what the students said. Member-check also helped to ensure conformability (Lincoln and Guba, 1985, p. 289). To ensure transferability, I provided detailed descriptions of the implementation process so that other teachers could adapt or modify it to suit their own classroom setting or context. Lincoln and Guba (1985) contended that transferability couldn’t be specified. Dependability is determined from credibility and conformability (Erlandson, Harris, Skipper & Allen, 1993; Lincoln & Guba, 1985). I used “thick descriptions” (Guba & Lincoln, 1985, p. 125) to support the findings made in this study to ensure dependability.

Summary

In this chapter, I presented the research methodology that was used for the investigation of how middle science teachers combined science and technology objectives in their middle school
science classroom to give students a STEM education experience. I provided a detailed
description of how data were collected. In this study the primary source of data was interviews,
which helped me as a researcher to enter into the perspective of each student and teacher
interviewed. The study employed an explorative qualitative research design and data was
analyzed using the constant comparative method. I have also discussed my epistemological and
ontological stance about integrated STEM education and learning. The next chapter presents and
discusses the findings from the implementation process, the teachers and students perspectives
from interviews and the framework (deduced from the implementation process and the
participants’ perspectives) for implementing integrated STEM instruction in the middle school
science classroom.
CHAPTER 4

FINDINGS

In this chapter, I will present the findings that emerged from the data analysis in this study. The findings for this study are structured under the following sections: teachers’ planning, collaboration, implementation, challenges/barriers, teachers’ perceptions, student perceptions, student learning, and assessment. For confidentiality reasons, all the names are pseudonyms.

The teachers involved in this study were: Mario, the technology teacher; Steve, the eighth grade teacher; Mitch, the seventh grade teacher; Shelley, the sixth grade teacher; and Doris, the fifth grade teacher. I followed three student teams in the eighth grade and audio-recorded three other eighth grade student teams’ discussions during their participation in the robotics activity in their science classroom. I also observed all the class sessions in eighth grade and two sessions in sixth grade. My classroom observations were guided by an observation protocol (Appendix A) that I designed prior to the start of the study. During the observations in eighth grade, I interacted (observing what they did and asking questions) with 72 eighth grade students. During the observations, I conducted mini interviews, in order to understand how they worked on the project. I was particularly interested in finding out if they had any plan for completing the project, roles among teammates, ground rules for making decisions or reaching consensus, the approach used to complete the task, whether there was any peer instruction, and whether there was collaboration among or between teammates. In total, I interviewed thirteen eighth-grade teams, including the ones that I followed and the ones that I audio-recorded. I did not interview any sixth grade students. Research question number one for this study is:
How do science and technology teachers restructure the middle school science curriculum and instruction in order to incorporate /implement objectives into science classroom activities using a teaching approach emphasizing robotics?

The findings that answered these questions are divided into subcategories for better understanding and simplicity. These findings are focused on the “what” and “how” and “why” of the integrated STEM project in the science classroom. The “how” includes planning, implementation approach (instructional approach and assessment). The “what” includes the kind of activities that were used and who developed them? The “why” includes the reasons why the teachers chose those particular activities? I determined that division of findings among these subcategories would better provide a detailed documentation of the process being studied. As I examined the data analysis of teacher interviews about how they went about incorporating robotics into their science curriculum, along with the classroom observations that I made in eighth and sixth grades, the results revealed that teachers’ descriptions of their implementation begins from the preparation, training or any support that the teachers received, continues through how the ideas for the activities were conceived, and includes the role of the teacher in the classroom (including any scaffolding that the teachers provided to the students). Relating to research question number 1, we will begin by exploring the implementation process.

The Implementation Process

In order to provide a better understanding of the results of this study, I broke the implementation process into various steps. The basis for these steps arose from an examination of the entire process of implementation from the analysis of teacher interviews and the classroom observations (sixth and eighth grades). The steps for the implementation process that emerged from this analysis included teachers’ preparation and the support they received, selection of
robotics activities and alignment of them with the science curriculum, and the actual implementation strategy in the classroom. Implementation in the classroom included the role of the teacher. The teacher’s role involved the type of support provided to the student and the assessment techniques used. Implementation in the classroom also included how students worked on the projects. All of these findings will be presented in the forthcoming sections.

Teachers’ preparation and preplanning of the Integrated STEM instruction and the support they received

Teachers collaborated and received support from Mario, the technology teacher

During the teacher interviews, I asked them how they went about the implementation of the integrated STEM instruction in their classrooms. Data analysis from teacher interviews revealed that each teacher mentioned that he/she spent more time than they usually do with their traditional science instruction in planning how to implement the robotics projects in their science classroom. This preparation included a short training (workshop) session that all these teachers said they attended. For example, Mitch, the seventh grade teacher, stated, “We had a two-day workshop where we learned how to use the NXT robotics program.” This workshop was sponsored by the school administration. A staff member from a nearby university engineering school with experience in robotics did the training. However, the workshop focused solely on how to build and program robots using the Lego Mindstorms NXT 2.0 kit. The kit that the teachers actually used in the project was the new EV3 kit, not the NXT 2.0. Lego Mindstorms EV3 is the third-generation robot in the Mindstorms robotics line, replacing the second-generation Lego Mindstorms NXT 2.0 robot. The "EV" label refers to the "evolution" of the NXT series.
Thus, the teachers who attended the training session did not find it directly relevant to the project. However, they all admitted that it did offer them some basic ideas about the construction and programming of robots. The eighth grade science teacher, Steve, also mentioned that he did receive the support of an engineering student from a nearby university. This student helped him in designing the acceleration project for his eighth grade class.

Another finding that emerged from the analysis of the teacher interviews was prior experience in incorporating robotics into science teaching. The teachers indicated that having prior experience would have been helpful, for instance, in selecting the robotics activity. However, only one teacher (Shelley) mentioned that she had worked with robotics in school before. The other teachers had no prior experience. Shelley said she was a faculty sponsor for a robotics club in her former school. Here is what she said:

Shelley: I did have a tiny bit of background from my being the faculty sponsor at my old school for the robotics program (Teacher Interview).

She then selected one of the activities (in collaboration with Mario) that she came across while working at the robotics club. This was the “Body Forward™” activity that she used in her sixth grade classroom. The rest of the teachers indicated that they had to depend on Mario, the technology teacher, to help select an appropriate activity for their classes. Here is what Mitch and Doris had to say about it:

Mitch: Mario and I had a little bit of time to do some planning and looked for the activity to be used (teacher interview)

Doris: He [Mario] helped to look for an activity that we had to use (Teacher Interviews).

These comments indicate that Mario played an indispensable role in the selection of the activity or project to be used in the classrooms. Thus, the science teachers and Mario worked
together to figure out which activity to implement in various grades. Even Shelley, who said she had some prior experience, and Steve, who had received support from a graduate engineering student, still emphasized that they had to collaborate with Mario during the planning because of his expertise (and their lack of expertise) in robotics technology. He has been working with students as their instructor and coach for the First Lego League tournament for many years. Thus, the teachers revealed that the collaboration and support from Mario was indispensable for the success of the project.

Some of the support that Mario provided included:

- Helping the teachers to select the relevant activities that would be implemented in each of the four grades.
- Participating in the introduction of the activities to each class; spending time during the classroom activities assisting the teachers who had difficulties in helping students with the robotics construction and programming.
- Answering questions from students about the robotics kit and the software program. (I observed as Mario and Steve introduced the project in eighth grade. During the introduction, they showed students a video about the importance of programming and explained various real-life tasks that robots can perform as well as the importance of relating technology to science and other STEM disciplines.)
- Being present to help the teachers and students with any technical difficulties related to the robot, such as troubleshooting, dealing with various recognized bugs, configuration management; chassis design options, drivetrains, positioning algorithms, connecting Lego sensors and their limitations.
In addition to collaborating with Mario, the science teachers also mentioned that they relied on him for assistance and support. Here are some representative statements, from Doris and Shelley that emerged from the interview analysis and showed how they relied on Mario’s support. Doris had this to say:

“I didn’t know anything about robotics. Mario [technology teacher] was my advisor, so to speak, and he was the one I went to when I found out I had to incorporate robotics into my classroom” (teacher interview).

Also, this is what Shelley had to say about the collaboration and dependence on Mario for support:

“There was a lot of collaboration with Mario, because he certainly has the most knowledge, so he was my go-to for questions and logistics, and how to do it” (teacher interview).

These statements suggest that these teachers not only relied on him but also that they also lacked the knowledge to handle this specific project. The statements also indicate how valuable his assistance or support was to the teachers.

*Teachers also did some self-training to prepare for implementation of the classroom instruction*

Mitch and Doris also indicated that they had done some studies on their own about robotics. In interviews these two teachers mentioned that they did some individual studies to better understand the project prior to its implementation. I have referred to this as self-training. Doris mentioned that she used the Internet to search for more relevant information about using robotics in the classroom and studied the EV3 kit at home, while Mitch said he took the robotics kit home to study how it works. Here are some representative statements from Mitch and Doris,
seventh and fifth grade teachers, respectively, that emerged from interview data analysis to support this finding. Mitch, the seventh grade science teacher had this to say about self-training:

Mitch: And so, we did have the chance to take a kit home and manipulate and work with it, build kind of the base robot and work with the programming software somewhat. So, I was able to kind of get a trial run personally before implementing it into the classroom with my students (teacher interview).

Doris reflected on her self-study by saying this:

Doris: As a support for robotics, I went out and researched and studied the history of it, the usefulness of it in this day and age (teacher interview).

These statements indicate the importance that the teachers attached to this project, their commitment to it, and their determination to help the students gain something out of it. These two teachers did not want to come to class without some background understanding of robotics. So they spent extra time trying to understand the robotics. However, they did not indicate if that self-training actually helped them during the project or not.

Restructuring the science curriculum and aligning it with the robotics project

I was interested to find out if the teachers had to restructure their science curriculum in order to fit the robotics activities in during the preparation for instruction. So in analyzing teacher interviews I looked for any statements that indicated whether the science curriculum was reorganized in order to incorporate the robotics project. In terms of restructuring the curriculum, the teachers stated that they selected the integrated STEM activities based on their existing curriculum. They did not revise their curriculum at all, but rather selected integrated STEM activities (robotics activities) and modified them to fit into the science topics that they were currently teaching. For instance, in the sixth grade, the teacher was teaching the human body
systems, and she wanted activities that would support or help students apply their understanding of the human body systems. So she chose the “Body Forward™” activity. In the fifth grade, the teacher was teaching astronomy and exploration of the planets. So he chose the “asteroid exploration project.” In the eighth grade, the teacher was teaching linear motion, so he chose the “acceleration project,” and finally in the seventh grade, the topic was optics, so the teacher chose “the color sorting project.” The results of teacher interviews also revealed that none of the teachers created any special or extra classroom time for these activities. They used their regular science class periods for this integrated STEM instruction. For example, in the eighth grade the teacher simply fit the instruction into his existing science periods and did not extend any class periods during the duration of the project. He also did not do any restructuring of his physical science curriculum.

**Nature and sources of the activities and aligning the robotics activities to the science curriculum**

The next finding that emerged from the analysis of teacher interviews and classroom observation was how the teachers decided which activities to implement in the classroom during the instruction planning. The results showed that some activities used were taken from the past First Lego League (FLL) tournament challenge activities and others from websites of institutions like Carnegie Mellon University that routinely design robotics based activities. Every fall, FLL releases a challenge, which is centered on a real-world scientific topic (FLL, 2014). According to the FLL website, each challenge is divided into three parts: the robot games, the project, and the FLL core values. Some of the past challenges have focused on topics such as nanotechnology, climate, transportation, and quality of life for individuals with physical handicaps (FLL, 2014).
Three of the teachers adopted some of the FLL past challenge themes. For example, in the sixth grade, the activity chosen for implementation was known as “Body Forward,” which was the FLL challenge theme for 2010. This challenge is based on the principles of biomedical engineering. In this challenge, students explore the world of biomedical engineering to discover innovative ways to repair injuries, overcome genetic predispositions, and maximize the body’s potential, with the ultimate goal of living a happier and healthier life (FLL, 2014).

As I analysed teachers’ descriptions of how they incorporated the robotics activity, the results showed that each teacher indicated that he or she wanted an activity that aligned with his or her science curriculum. This influenced their choice of the activity or project to be used in the classroom. They wanted an activity that they considered to be aligned with their science standards and that thus they could use to give their students an integrated STEM experience. For example, the sixth grade teacher had this to say about incorporating the robotics into her life science lesson:

Shelley: Well, when we were first told, I thought, well, how was that going to work? Because I have a very life science based curriculum and I didn’t just want to drop it [robotics] in the middle and not incorporate it [life science] into it, it had to make sense to me that it was in there. So I kept thinking of how could we tie it into body systems and then that is what I ended up doing. They built and programmed their robot to fix something in a body system, so they either cleared a clot in a vein, or they fixed a broken bone, or they regenerated nerve cells, or they had a pill dispenser where they dispensed the correct amount of pills. So that was my tie-in. And we’re also talking about engineering all the time, I just do that as a theme all year talking about STEM projects and engineering and so we’ve looked at a lot of inventions and technology, so that was
another kind of smooth transition. We’d been talking about people that fix things and this is a way, so it worked. It worked actually great to tie in the health, the body systems and the engineering together. I was really pleased, because at first I thought, I’m not going to make this work with my curriculum, but I did, it was great (teacher interview).

All of the activities chosen involved science objectives, as can be seen in table 4.0. For instance, in the eighth grade the science objectives were for students to understand and apply the concepts of acceleration, deceleration, directional acceleration, and velocity by programming their robots to follow a predetermined path. In the sixth grade, the teacher wanted the students to understand and apply their understanding of the physiology and anatomy of the human body system to design a robot that would perform certain tasks in the body like repair a broken bone, and dispense pills.

Another activity that was used in the seventh grade was based on astronomy concepts. This was a problem-based activity that had to do with asteroid exploration. It was fitted into the ongoing unit of the solar system in the seventh grade. The seventh grade teacher in this study reported that the activity was chosen because it suited the science content they had already covered in the classroom about asteroids and their presence in our solar system and space in general. The eighth grade activity was directly related to the concepts of acceleration and linear motion in general, where students had to program their robot to follow a certain track determined by their science teacher. Students had to build, program and test their robot. Table 4.0 shows a summary of the various activities used.
<table>
<thead>
<tr>
<th>Grade level</th>
<th>Activity</th>
<th>Technology objectives</th>
<th>Science objectives</th>
<th>Reason for choosing the activity</th>
<th>Direct observation by me (the researcher)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Color sorting</td>
<td>Programming</td>
<td>Understand how various colors are produced</td>
<td>Help support student understanding by relating color sorting using sensors to why various colors are formed</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>Body Forward</td>
<td>Programming</td>
<td>Understand the anatomy and physiology of the human system</td>
<td>Support student understanding and discover innovative ways to repair body injuries and maximize the body’s full potential</td>
<td>Partially (observed two of the seven class periods)</td>
</tr>
<tr>
<td>7</td>
<td>Asteroid exploration and the solar system</td>
<td>Programming</td>
<td>Understand that planetary images contain valuable information that requires interpretation. Be able to recognize each planet by its unique and identifiable features</td>
<td>Support student understanding of the solar system</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>Acceleration activity</td>
<td>Programming</td>
<td>Understand and apply acceleration, velocity, deceleration, and directional acceleration</td>
<td>Support student understanding of motion</td>
<td>Observed all sessions</td>
</tr>
</tbody>
</table>
Once the teachers had selected the activity and were certain that it aligned with their science standards, they proceeded to implement the instruction in their classrooms. This brings me to what happens in the classroom, which I will refer to as the implementation strategy. Implementation included the teacher’s role, which I deduce from the teacher’s actions and behaviors in the classroom, and what the students did or how they worked on the project, based on my observations of student actions and behavior during their participation in the project.

**Instructional and Implementation Strategy that the Teachers Used**

*Instructional approach used was student-centered, project-based and problem-based*

In this study I adopted Felder and Brent’s (1996) definition of student-centered instruction as a broad teaching approach in which students are actively involved in learning instead of being lectured to and are responsible for their learning. I also used Weimer’s (2002) characterization of student-centered learning. Weimer outlines the role of the teacher in student-centered instruction to include encouraging the students to do more discovery learning and to learn from one another, constructing authentic real life tasks, and motivating students to participate in the tasks. In order to determine the instructional approach employed, I used data from teacher interviews that related to descriptions of their approaches and from my observations of the actions and behaviors of the eighth grade teacher in the classroom.

During the teacher interviews, I asked them to describe the approach that they used to incorporate the technology objectives and the science objectives in their classroom. I also observed all of the class sessions in the eighth grade and two sessions in the seventh grade. I then analyzed the teacher interviews for descriptions of their implementation approach. The common features of the implementation approach that emerged from all the descriptions showed that they each started the implementation with a preparation stage, which consisted of introducing the
project to the students. For example, in the eighth grade I observed that the technology instructor and the science instructor jointly introduced the project. In the introduction, the students watched a video about programming and the two teachers talked to them about the importance of coding or programming (the two words were used interchangeably by the teachers) in society. Then the physical science teacher reviewed student prior knowledge by asking them questions about velocity, which was the topic they had just completed prior to this project. He explained what the students were expected to do in this project. Then he placed students in various teams. Each team was made up of two to three students. The teacher distributed materials to the students, for example each team’s robotics kit and the rubric for assessments, and showed students the diagram of the pathway (shown in figure 4.0) and the actual pathway (pictured in figure 4.1), which were placed in the classroom. The students had to maintain their teams for the total length of the project (three weeks in each grade level). Based on interviews with teachers of other classes, this introduction parallels what happened in the classes that I did not observe. After students watched the introductory video about programming, they were assigned to teams, provided with the robotics kits, showed where to test their robots and told how the project would be assessed, and then they started to work on their project.

During this implementation, I wanted to understand the instructional strategy that the teacher was using. I did this by observing the teacher’s actions in the classroom. For instance, I was thinking of the teacher’s actions in terms of questions: did he lecture to the students? Did he move from one team to the other asking students questions? Did he provide feedback to the students as they worked? I also asked the other teachers whose classes I did not observe about the implementation approach that they used. I then coded these responses for statements that indicated the actions and behavior that they exhibited in the classroom. For instance, when
Shelley said that she “had to step back and let the students do the learning and only provided them with clues to come up with the solution,” I coded this as “encouraging students to do discovery learning.” When Mitch said, “I placed [the students] in teams and encouraged [them] to work together and assist each other,” I coded this as encouraging students to learn from each other. In the teachers’ descriptions, they also made statements such as, “I moved from one team to the other, asking them questions about what they were doing,” “I allowed students to actively share their experiences with me” and “I made sure each student was participating by asking them to rotate roles.” I coded all of these to indicate that they were related to teacher promotion of student-centered learning.

The teachers also mentioned during the interviews that while working on the projects, the students solved problems, answered questions, formulated questions of their own, discussed in their teams, offered explanations to their teammates and to the teacher, debated in their teams, and brainstormed during the activity. Here are statements from Mitch and Shelley, which represent what these teachers said about the instructional approach:

Mitch: During the activity, students were very involved in solving problems in the task. You know, in their teams they brainstormed, asked each other questions, came up with solutions, discussed among themselves, and explained their ideas pretty well. In fact they were very active in the learning process and I am glad we, Mario and I, designed the instruction to encourage that. I do believe that this was the case in other classes.

Shelley: I had to sit back and let the students do the work. They took the responsibility for their own learning.

Steve: I used open-ended problems in the class and asked them open-ended questions (Teacher Interviews).
Across the board, each of the teachers offered similar descriptions of their instructional approaches and of what their students did. On no occasion did the teachers mention any lecturing. When I summed up the actions that each teacher indicated that he/she used, I came to the conclusion that the teachers were using the student-centered approach. This was based on Weimer’s (2002) characterization of student-centered learning, mentioned previously, which includes encouraging the students to do more discovery learning and to learn from one another, constructing authentic real life tasks and motivating students to participate in the tasks.

I did observe the eighth grade teacher move from team to team encouraging the students to think critically and offering clues to help them learn the underlying concepts of acceleration. For example, he stated, “You have to think of how to make your robot move smoothly on the track,” and I coded this as prompting students to think critically. He also moved around encouraging students to participate in the project by asking them to rotate roles within the team. This teacher moved from team to team, interacting with the students and asking them questions about the project. He also answered a question from a student about the project. In no instance did I observe him lecturing students. All of these observations were coded to mean that the approach was a student-centered one.

In Team A, I did observe that all the students participated in discussions or contributed ideas toward the project: they asked questions, offered explanations of any suggestions, brainstormed and came up with ideas on how to program the robot. This parallels what happened in Teams B and C. The students planned how to complete the tasks, they brainstormed and came up with ideas, programmed their robots, and tested and refined their ideas.

I therefore concluded that the instructional approach employed by the teachers in this study (grades 5, 6, 7 and 8) was a student-centered approach. The instructional approach was
also problem-based, and project-based. This is because all the lessons in the four different grades involved a project and each project had problems to be solved. This characterization was deduced from my understanding of the various projects that the teachers used in their classes. Each teacher said he or she presented their students with a real-world project that involved a problem and asked the students to build their robot and use it to solve that problem or accomplish a task. I have summarized the activities they used in table 4.0.

**Teacher’s Role in the Classroom During the Project**

*Teachers placed students in teams*

One of the teachers’ roles that emerged from observing the eighth grade classes and from mentions by the fifth, sixth and seventh grade teachers in interviews was that of placing students in teams using some specific criteria. This was done at the very beginning of the instruction for the robotics project. The teachers placed students in teams, most teams consisting of two students, but a few with three students. For example, in the eighth grade, 90% of the teams consisted of two students and 10% of three students per team. Students maintained these teams till the end of the project. Teachers also described criteria they used in assigning students to teams. For example the seventh grade teacher, Mitch, described how he carefully arranged the students in pairs based on their prior performance in class, interest, perseverance and personality type (an informal evaluation of the students applied by the teacher). This teacher stated his reasons for pairing up contrasting personality types as follows:

Mitch: Somebody that gets frustrated really easily is paired with somebody that is very patient; people that I know their strength in building with somebody that I know that doesn’t build at all; somebody that is a computer whiz with somebody that hates computers (teacher interview).
The approach was somewhat different in the fifth grade, where the students were arranged in groups of four. In this case the teacher stated that the reason for placing them in this size teams was for division of labor, where two students were assigned to a particular task such as building a certain portion of the color sorter while the other two built other sections. They then combined their various sections to form the project. So, according to the seventh grade teacher, Doris, “it was a group of four working for a single project but they had their individual projects at the table” (teacher interview).

In the two classrooms that I observed, I noticed that these classrooms were not managed in the way one would think of a traditional classroom where things are ordered, quiet and systematic. These were classrooms where students were busy explaining, debating, brainstorming and moving around from the testing area to their work area or desk. Entering these classrooms, one might be tempted to say that there was no control of the students; however, that would be a mistake, because the teacher maintained control. The teacher could get the student attention in a matter of seconds.

**Teacher as a facilitator**

One of the roles of the teachers that emerged from the data analysis was that of a facilitator. To identify this role I used the definition of teacher as a facilitator proposed by Silberman (1971): A facilitative teacher is one who will guide, prompts, and motivates students to learn (Silberman, 1971). In order to determine if the teachers were facilitators, I asked them to describe how they managed their classroom instruction during the project. In their responses, I coded statements that indicated that they guided, instigated, and motivated students. For instance when a teacher said, “I asked students open-ended questions which permitted them to think critically,” I coded that as indicating that they instigated or prompted the students to learn by
considering the evidence available to them. Statements such as “I provided the students with clear instructions on what they were expected to do” were coded to indicate that the teacher guided the students to learn. For me to conclude that a teacher was a facilitator, I had to be able to code statements from his or her responses that indicated that he or she guided, motivated, and instigated. In the end I could only identify and code such statements from the sixth and eighth grade teachers. For the fifth and seventh grade teachers, I did not find sufficient statements about guidance, motivation, and instigation to reach the conclusion that they were facilitators.

The sixth and eighth grade teachers, who I concluded from their responses, were facilitators in the classroom, were also the ones I actually observed. During the observation I recorded verbal expressions that they used during the project. These expressions were then analyzed to find out if they were able to motivate, guide, or instigate students to learn. Some of the expressions included “you are getting there,” “you have done a great job so far.” These were coded to indicate verbal statements that were intended as motivation for students. Here are representative questions from Steve that emerged from the classroom observations and which focused on stimulating students to think: “why is your robot not accelerating when it is supposed to?” and “why do you have a power of 30 and four rotations here?” These questions were coded as providing guidance and instigating students to think critically. The teacher stated that his reason for asking such questions was so that the students would think for themselves. Shelley used statements such as “make sure your program is saved” and “you can test your robot and make changes.” These were coded as providing guidance.

In their responses, the teachers also explicitly articulated how they acted as facilitators. Here is a representative statement from Shelley that emerged from the data analysis:
Shelley: And it was very interesting, I try not to do more and more, and I said to myself that I am the facilitator instead of the teacher, so it was very - step back and let them do it, and to watch them do it and do it successfully and find success and for me to step back, it was powerful to see, and humbling in a way, too, that if you give them what they need, they can create the answers, and humbling that they don’t need you to tell them every single thing (teacher interviews).

This suggests that it was not easy for these teachers to take a different role as a facilitator instead of as a teacher. However, these teachers believed that it was beneficial for the students when the teacher’s role in such activities was that of a facilitator.

*Teachers Assessed Student Learning in the Integrated STEM Instruction*

Before I present this finding, I would first of all define the tasks that were used in the eighth grade project. Table 4.1 shows a breakdown of the robotics project in the eighth grade. The overall task or project involved five tasks. Each task had at least one problem that the students had to identify and solve.
Table 4.1
Defining the Tasks that the Eighth Grade Students had to Complete in the Eighth Grade Project

<table>
<thead>
<tr>
<th>Task</th>
<th>Title</th>
<th>Description of the problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>Building the robot.</td>
<td>Students had read and followed the instructions on the robotics instruction sheet to build the robot. The challenge that most students faced here was to read the 2D diagrams and convert them to a 3D robot.</td>
</tr>
<tr>
<td>Task 2</td>
<td>Program the robot to accelerate.</td>
<td>The robot had to accelerate over a fixed distance on the pathway</td>
</tr>
<tr>
<td>Task 3</td>
<td>Program robot to decelerate.</td>
<td>There was a fixed distance over which the robot had to decelerate.</td>
</tr>
<tr>
<td>Task 4</td>
<td>Program robot to move at directional acceleration.</td>
<td>The robot had to make a directional acceleration (move at constant speed but change direction by making a turn). The turn was not supposed to be a right-angled turn, but a turn at an angle less than ninety degrees.</td>
</tr>
<tr>
<td>Task 5</td>
<td>Program robot to stop as close to the obstacle as possible (about three inches way from the obstacle).</td>
<td>The robot had to stop as close as possible (no distance specified) to the obstacle without hitting it.</td>
</tr>
</tbody>
</table>
In tasks 2 to 5, students manipulated variables. These variables included: time, number of rotations of the wheels, number of turns and angle of turns, number of steering moves controlling the angle of turn, and power. It was observed that various teams used time differently. For example in Team A, they changed the time for a chosen number of rotations or time required to cover a given distance. For the number of rotations, students had the options of programming a different number of rotations for each wheel or just programming the same time and number of rotations for all the wheels.

Data analysis of teacher interviews and classroom observations, which focused on finding out if the teachers assessed students learning, showed that during the interview three out of the four science teachers mentioned that they assessed student learning while the students were participating in the robotics activity. These teachers assessed students using different techniques. These techniques emerged from what the teachers said during the interview and from what I observed in the eighth grade. Some assessment techniques were informal, as in the eighth grade where I observed that the teacher went around from team to team asking questions of the students. The teachers also mentioned that they used formal techniques; for example, Shelley indicated that she used a rubric. Only the fifth grade teacher stated that she did not assess the student learning during the robotics activity. She explained that this was because she never really understood how to incorporate the project into her science objectives, though the tasks, as I understood from her description, paralleled those in eighth grade.

The eighth grade teacher stated that he assessed the student learning formally using a rubric, which was divided into two sections: one section had to do with task accomplishment (80%) and the other with peer evaluation (20%). Within that breakdown of scores, the following will show how task completion was used to give the students a maximum number of points from
within the 80% of the total points that was based on robotics tasks. The grades for tasks were broken down as follows: 75% (or 60 points from a possible 80) was the maximum total score if the students only completed the construction of the robot, 80% was the maximum total score if the students completed the construction and also were able to program their robot to positively accelerate, 85% was the maximum total score if the students completed the construction, and also achieved positive acceleration and negative acceleration. A 90% total score was the maximum possible if the students completed the construction and controlled the robot through positive acceleration, negative acceleration and also directional acceleration. The maximum total score of 95%-100% was possible if the students completed the construction of the robot, used it to accelerate, decelerate, perform directional acceleration, and also were able to program the sensor to come to a stop as close as possible to the wall (obstacle) without touching it. As for how close to the obstacle it had to be in order to receive credit, the teacher did not specify. “Close as possible” was estimated by the teacher, and from my observation was three inches or less away from the obstacle. Hence, the teacher gave credits to teams whose robot was within three inches from the obstacle. For each of these tasks, when students felt sufficiently confident after testing their robot, then they indicated to the teacher that they were ready to demonstrate it and the teacher would observe and notify them if they had accomplished the task or not. If they did not accomplish the task, then they would have to continue working on their robot. It was observed that many students made several attempts before getting it right. However, about 70% of the students who contacted the teacher were able to have the robot satisfactorily complete the task in fewer than three attempts. This level of success resulted from the testing of the robots that students completed before calling on the teacher for observation and feedback.
For peer evaluation, the results showed that the teacher provided each student with a worksheet to record (describe) their own contribution to the project, stating explicitly what he/she did, and the partner signed off to confirm that the record was accurate. Then the teacher graded the student work. Results from the teacher interviews about the student performance revealed that all of the students in the eighth grade achieved at least two tasks, which resulted in grades of high B’s and A’s.

Another example of assessment that emerged from the data analysis was used in the seventh grade class. In the seventh grade, analysis of teacher interviews about assessment revealed that the science teacher and the technology teacher worked together to implement the asteroid exploration activity. I was unable to observe this class, but what I know from interviewing the seventh grade teacher is that this activity had a certain point value awarded according to the number of objectives that the students achieved. These objectives were at some level parallel to the tasks described for eighth grade. The seventh grade science teacher explained that the students also were assigned to complete periodic journal entries and reflective writing pieces where they wrote about what they believed they learned each day from the project. The students also wrote about how they completed the project as a team, evaluating each teammate’s performance. This was done using an online Google student survey form that they completed. The survey focused on how each student interacted and how they felt about working with their teammate(s). The teacher told me that they used the survey, but I have no knowledge of the results or of any sample items from it.

In the above section, I discussed the implementation process, which emerged from the data analysis. In particular, I have presented the findings on how the teachers planned the instruction, the instructional approach they used in the classroom, and their assessment
techniques. In the next section, I will present the findings on how the students worked on the project. This is still considered part of the implementation process.

**How Students Worked on the Project**

In order to understand how students worked on the project; that is if they worked as a team, collaborated with each other, and were engaged in the project, I followed three teams and also walked around from team to team asking the members questions and observing the interaction of teammates. Thus, findings about how the students worked on their projects are based on analysis of three sources of data: the descriptions that the teachers offered during the semi-structured interviews; the observations that I made in the eighth and part of the sixth grade classes; and the transcript from student group discussions and interviews during the project.

During the project, I followed three teams of eighth grade students and also audio-recorded their team discussions. I referred to these teams as Team A, Team B and Team C. Team A was made up of two girls (Abigail and Natalie); Team B consisted of two boys (Jimmy and Ty); and Team C was made up of two girls and a boy (Ellie, Sally, and Tom).

Results of classroom observations also showed that all the students worked as a team and collaborated with teammates in order to complete the project

Teachers placed students in teams and informed them that the project was a team project and so the students were obliged to work as a team. What I wanted to find out was whether there was collaboration among teammates. In order to determine if students collaborated with their teammates, I used the Merriam Webster online dictionary’s definition for collaboration: “working with another person or group in order to achieve or do something.” Collaboration or working together here involves supporting and encouraging each other. I analyzed the expressions that students voiced during their teamwork to see if they worked together or worked
as individuals in the team. If students made statements that meant that they were offering support to each other, then I coded those as supportive statements, which implied that the students collaborated. Further analysis of the classroom observation data about student group interactions during these activities revealed some of the expressions that students continuously used and which were indicative of offering support, showing that they had problems or challenges, offering encouragements or ideas to their teammates, collaborating in the team, and focusing on team achievement. Some of the representative expressions that emerged from the data analysis are shown in table 4.1.

I also coded the use of “let’s” or “we” by students in their team discussions as indicative of working together. Here are some representative expressions from eighth grade student team discussions in which they used “let’s” and “we”:

“It can’t go that fast, let’s reduce the number of rotations,” “it can’t go that fast,” “hold on, don’t go that fast,” “it seems pretty good, let’s just start all over,” “Let’s make it do two more rotations.” “We need to reduce the speed by changing the number of turns.”

I considered expressions like these to represent the student desire and determination to get the project done correctly together as a team. As I analyzed the classroom observation data, the results indicated that 100% of the students I observed used expressions similar to those shown in table 4.2, and also continuously used “let’s” and “we” in their team discussions.
Table 4.2
Representative Student’s Expressions that Emerged from the Data Analysis of Student Interviews

<table>
<thead>
<tr>
<th>Support Expressions</th>
<th>Student problems/challenges Expressions</th>
<th>Encouragement/ideas Expressions</th>
<th>Collaboration Expressions</th>
<th>Achievement Expressions</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I will look for the right part that fits there”</td>
<td>“I can’t get it to move smoothly”</td>
<td>“Let’s make it do two rotations”</td>
<td>“Let’s make it turn after the two rotations”</td>
<td>“It seems pretty good”</td>
</tr>
</tbody>
</table>
Furthermore, data analysis from classroom observations and student and teacher interviews about the approach that students used to complete the project also revealed that all the students worked together to attain shared goals (collaborative work) in their various teams. In fact there was no instance during my observation and during the student and teacher interviews when I noticed or somebody mentioned that a student was not collaborative. The results showed that in many of the different teams observed in the eighth grade, all of the students worked together to identify what they had to do as a group during the entire project, and they brainstormed and planned together. Together they decided what course of action to take in order to attain their goals and were able to implement and monitor their plan to make sure that they reached those goals. For those specific three teams that I followed, each team member functioned well as part of the team. They listened to each other’s opinion and resolved differences amicably and respectfully. They expressed their ideas openly to their teammates. Here is a representative conversation between two eighth grade students, Nicole and Eve, about working together to get their project done:

Nicole: We need four rotations and the time set at twenty-five seconds, and the second one we need a power of ten and the time twenty-five seconds and rotations four. That is the one before the turn, then after the turn we need another steering move.

Eve: Let’s test the first rotations before adding the remaining four.

Nicole: All right. Let’s do it. Let’s make it work (student interview).

These students use of “let’s” suggests the team spirit and collaboration that existed between these students.
Integrated STEM Instruction enabled students to apply science concepts to the project.

As I observed these students, I asked them questions about whether they applied any science concepts in their robotics project. In addition to these three teams, I also interviewed ten other teams in the same grade in the physical science by the end of the entire project. During the analysis of the student responses to the question about whether they applied science concepts, I used the following criteria to code their responses: either a student explicitly stated that he or she or they (referring to the student’s team) applied the science concept, or the student described how he/she/they applied the science concept. Here is an example of what an eighth grade student said: “We applied the knowledge of acceleration in our project.” This is an example in which the student explicitly stated that they applied a science concept. Here are examples of some of the student statements that I coded to mean that they applied the concept of acceleration:

Leo: We also applied acceleration, applied the concept of acceleration, when we programmed our robot.

Ellie: To me that was when we used acceleration. We could not just program our robot without making use of velocity, positive acceleration, negative acceleration and the other one…directional acceleration.

Trish: We also made use of acceleration, positive acceleration and directional acceleration throughout our project (student interview).

These statements all suggested that the students applied the concept of acceleration to their project. The results of the analysis showed that 70% of the students that I interviewed made similar statements about applying acceleration and speed. The remaining 30% of the students did not mention anything about acceleration or any other science concepts that they applied during the interviews. Those who mentioned that they applied the concept of acceleration explained that
in order to program their robots, they had to base their decision on whether they wanted the robot to accelerate, decelerate, and move at a constant speed or stop. Representative explanations that emerged from these data analyses illustrating how these students applied science concepts came from one of the thirteen teams of eighth grade students that I interviewed. The two students on this team explained that in order to program their robot to move along the predetermined path they had to change (increase) the power inputs and the number of rotations for the robot to accelerate. They also recognized that they had to reduce the power and the number of rotations over some time intervals for it to decelerate and that they had to keep the power and number of rotations fixed for it to move at constant speed. This indicated the student understanding of the science concepts of acceleration, deceleration and directional acceleration, because without that science knowledge, they would not have gotten (programmed) the robot to do what they wanted it to do. Students also made use of the ratio language to explore the relationship between distance travelled by the robot and wheel rotations.

**Students employed different approaches to complete the tasks**

As I observed the students in eighth grade, I asked them about the approach they used to accomplish the tasks. In Team A, for example, the students explained that they worked together with other members of the team to create a strategy to accomplish the specific tasks required in the project. The completion of the tasks outlined in the strategy allowed them to accomplish the tasks within the overall problem outlined for them. The results from classroom observations showed that 60% of the students said they had actually put in place some sort of strategy. The same 60% of students further indicated that in creating their strategy, they viewed the robotics project as a “design cycle.” In the context of this project, design cycle means the students followed steps to complete each task within the project. This also means that they were prepared
for an “iterative” approach in which they would try one approach and then test and then modify and try again. They said each task had some steps to follow. For example, Team B members explained that they first completed the acceleration task before proceeding to the deceleration, then to the directional acceleration, and concluded with the robot stopping an inch away from the obstacle. Within each design cycle, Team B studied the problem within the task, brainstormed possible ways to manipulate the variables, changed the variables, tested their robot, made observations on the robot’s movement, went back to their team’s table and made changes on their variables input and retested the robot. They continuously developed and modified their ideas. They also tested their design continuously and systematically throughout the entire process. These Team B students made an average of three attempts in each task (before getting the robot to accelerate, decelerate and move at constant speed in a curve). The order of the tasks as enacted by the students was not linear.

The Team B students explained that they started off by building their robot. After building the robot they started working on each task. For example, they worked on the acceleration task first and made sure that their robot could accelerate, before proceeding to the deceleration task and then the directional acceleration task and so on. In each task the two students on this team would break down the problem into the smaller pieces necessary to solve it. For example, in the directional acceleration task, they programmed the rotations for each front wheel of the robot and the time that it would take a wheel to make a rotation. Unlike in the acceleration task where they programmed the wheels to make same number of rotations per given time, they explained that in the directional acceleration task, they programmed the wheel on the “outside” of the corner or curve to make more rotations per unit time than the wheel on the inside of the corner. With this approach, they made about three attempts before getting their
robot to attain the objective (making a directional acceleration). Only 10% of teams interviewed mentioned that they followed steps similar to Team B’s. I referred to the approach described by Team B as the “analytic approach.” The remaining 90% of the students that I interviewed stated that they made an average of six attempts on this task before finally getting it to work.

An example of the 90% of remaining student teams comes from Team C, where Tom explained that in their strategy they agreed to brainstorm and pool ideas from each teammate, then analyze the effectiveness of those ideas by using them to program and test their robots. If the robot did not move the way they wanted, then he explained that they had to modify their ideas by changing the previous inputs on their program. He also mentioned that each student in their team had to explain his or her ideas and answer any questions from their fellow teammates. All the teams interviewed mentioned that usually one member of the team would bring up an idea and then after discussion the remainder of the team would agree to implement it. Figures 4.0 and 4.1 show the theoretical and actual pathways that were used in the eighth grade.
Figure 4.0: The theoretical diagram of the pathway for the robot to follow.
Figure 4.1: Picture of the actual pathway that was used in the eighth grade classroom
Students were also able to integrate robotics concepts with other STEM domains

Another finding that emerged from the classroom observation data analysis revealed that the three teams I followed were able to integrate robotics concepts with other STEM domains. By integration, I mean the students could relate concepts from robotics to concepts from other STEM domains. For example a student could build and program the robot using both programming and science knowledge by showing that programming the robotics to change the number of rotations with a consideration of time would lead to acceleration or deceleration. In this case he or she has linked change in rotations over time to speed of the robot. For example, students from Team B explained how they related the change in the number of rotations over time to positive acceleration by stating that in order to make their robot accelerate, they increased the number of rotations of the wheels over time and also augmented the power of the robot. So, they related the change in number of rotations over time to speed and then indicated that as they programmed the number of rotations to keep changing with time, their robot accelerated. They stated, “We measured the distance on which the robot had to accelerate and converted it to the number of rotations that the wheels on the robot had to make.” Thus the students understood the relationship between the correct amount of movement of the robot and the circumference of the wheels. The students further explained, “We divided the total distance that the robot needed to move by the circumference [of the tire] to get the number of rotations.” The number of rotations of the tire in a given amount of time was presented to the students as a programming concept (or module of programming) within the robotics software that they were to use.

As I listened to Team B’s discussion, Ty suggested that if they increased the number of rotations within a unit of time then it could cause the robot to move faster. Ty and his teammate then tried the idea and realized that Ty’s prediction was right. Thus these students concluded that
there was a link between the number of rotations per unit time and how fast the robot could move (the greater the number of rotations they programmed the faster the robot moved). The students also showed me the calculations they made to figure out the number of rotations based on the distance measured. This act of figuring out how to do the calculations, according to the students, was without the teacher’s help. The students created equations 1, 2, 3 and 4

Distance travelled, \( s = \) number of rotations, \( r \), x the circumference of wheels, \( c \), that is,
\[
s = rc
\] ...
Equation 1

From Equation 1, the number of rotations = distance travelled /circumference of wheel, \( r = \frac{s}{c} \)

..........................Equation 2

Velocity, \( v = \frac{s}{t} \) ..... Equation 3

and

Acceleration, \( a = \frac{s}{t} = \frac{rc}{t} = \frac{v}{t} \) ....Equation 4.

These equations helped the students to convert distance to be travelled into number of rotations of the wheels. This was necessary because the robotics program could only allow students to manipulate the number of rotations (not the distance) and the time per rotation. Here is a representative explanation that emerged from the data, in which the students explained how they linked the concept of acceleration to other concepts:

Caleb: In our group we thought about how we were going to link acceleration to the diameter of the wheel of the robot and the power on the acceleration block. Then one of our team members proposed that we measure the distance and use it to calculate the number of rotations. So we measured the distance and converted it to the number of rotations by dividing it by circumference. It took us more time to do the mathematics, but we got it and that was awesome (student interview).
This suggests that these students were able to connect mathematics concepts to science and technology concepts. As I observed other teams, I noticed that all the three teams (A, B, and C) that I followed made similar connections. Furthermore, when I interviewed ten other teams, six of them offered similar explanation of the connections they made. Thus nine out of the thirteen teams (70%) were able to make these connections. Table 4.3 shows how these connections were observed.
Table 4.3. How various teams made the connections of concepts in the robotics project

<table>
<thead>
<tr>
<th>Team</th>
<th>Connections made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team A</td>
<td>Mentioned that they related the number of rotations per unit time to how fast the robot moved. Related the change in the number of rotations over time to positive acceleration</td>
</tr>
<tr>
<td>Team B</td>
<td>They stated that increased the number of rotations of the wheels over time and also augmented the power of the robot to make the robot accelerate and also related the change in the number of rotations over time to positive acceleration</td>
</tr>
<tr>
<td>Team C</td>
<td>They related the circumference of the wheel and number of rotations to the distance travelled by multiplying the circumference by number of rotations to get the distance travelled. In order to get the velocity they changed the number of rotations over time since the circumference remained constant (same wheel was used).</td>
</tr>
</tbody>
</table>
These students were cognitively capable of relating change in speed per unit time to specific programming commands. For instance, data analysis of classroom observations revealed that using the programming commands, Team B applied a certain amount of power per unit time to the robot’s motor. This power enabled the robot to move at a particular speed for a certain amount of time and a number of rotations determined by the students. This result warranted more observations, and so I observed more students and analyzed the data, but the results showed that most of the students could not explicitly state these connections (equations 1 and 2) the way Team B did. Therefore, from the data analysis, 70% of teams interviewed stated that they made similar connections to what team B did. The connections that they made included:

- In Team B, they linked the change in the number of rotations of the wheel per unit time to velocity. For acceleration, they programmed the number of rotations per unit time to change per unit time. For example, they had 10 rotations in 5 seconds as their velocity and then programmed the robot to change from 10 rotations in 10 seconds (1 rotation per second) to 15 rotations in 5 seconds (3 rotations per second), to 20 rotations in 4 seconds (5 rotations per second). This made the robot accelerate.

These students explained that some members in their teams brought up the ideas that they actually measure the distance and do the conversion. The other students listened to the suggestion and offered their own point of view. On analysis of these groups’ talk, as audio recordings revealed, these students also spent more time brainstorming which approach would be more efficient. They listened to each other and asked questions before enacting a solution. By contrast, in the other groups students spent less time discussing which possible solutions might be most likely to work, and more time just enacting any solution that occurred to them.
**Student engagement in the project**

I defined “engaged” students as those who were involved in the project at various levels. This definition is adapted from Astin (1985), who described engagement as “student involvement.” When coding the classroom observational data for engagement, I used the activities Garrett (2011) proposed for detecting student engagement, which include: participating in learning activities; involvement in class discussions; asking questions; debating; responding to others’ comments; bringing questions and problems to class; making connections with other texts and writers, and probing deeply into a text or research. In this study, I grouped the above into four subgroups that better represent what students did in the robotics activity:

1. Construction of the robot
2. Programming the robot
3. Testing the robot
4. Team discussions

Table 4.4 shows how the above activities are linked to Garrett’s activities
Table 4.4. Linking the Eighth grade activities to Garrett’s activities

<table>
<thead>
<tr>
<th>Class activities</th>
<th>Garrett’s activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction of the robot</td>
<td>Participating in learning activities</td>
</tr>
<tr>
<td>Programming the robot</td>
<td>Participating in learning activities, asking questions, debating, making connections with other texts and writers</td>
</tr>
<tr>
<td>Testing the robot</td>
<td>Participating in learning activities</td>
</tr>
<tr>
<td>Team discussions</td>
<td>Involvement in classroom discussions, debating, asking questions, bringing questions and problems to class</td>
</tr>
</tbody>
</table>
There were various types of involvement that students exhibited in the eighth grade teams. In some teams, students tended to be leaders, while others were followers. Participation in the project included being a member of a team, which everyone was. Within that team, some students became very engaged in assembling the robot, for example, and other physical activities, such as carrying the robot over to the track and setting it down to see if it would do what it was supposed to do. Others were very engaged in figuring out how to program the robot. These are the kind of activities that denoted involvement in this study. Table 4.5 shows some representative examples of how students in Teams A, B and C were involved in the activity.
Table 4.5 Subgroup of Eighth Grade Activities and Examples of How students were Involved in Them.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Examples of how students were involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction of the Robot</td>
<td>This was the first activity in the project. It involved selecting the correct parts from the EV3 set and using the instruction guide to build a robot.</td>
</tr>
<tr>
<td></td>
<td>o In team A (made up of two girls, Abigail and Nathalie), Nathalie was the “handy” person. She tended to do most of the construction. She was the person who read the instructions from the EV3 instruction guide and then asked Abigail to look for the parts and give them to her. Then Nathalie would identify where the parts should be connected and perform the connection. For example, she determined the ports for the various USB cables.</td>
</tr>
<tr>
<td></td>
<td>o Abigail tended to work 90% of the time while standing, while Nathalie spent 90% of the time seated. 90% of the time, Abigail was the one who located the required parts from the EV3 set.</td>
</tr>
<tr>
<td></td>
<td>o Nathalie was the leader in team A and Abigail was a follower.</td>
</tr>
<tr>
<td></td>
<td>o In team B (a team of two boys, Jimmy and Ty), I would say they were complex personalities, where each person tried to claim the leadership role. In the end, they were co-leaders.</td>
</tr>
<tr>
<td></td>
<td>o In team C (a team of one boy and two girls: Tom, Sally and Ellie), Tom tended to be the leader and Sally and Ellie the followers.</td>
</tr>
<tr>
<td>Programming the Robot</td>
<td>After, constructing the robot, the students had to learn how to program it. They needed to “tell” the robot what they wanted it to do.</td>
</tr>
<tr>
<td></td>
<td>o In team B, Jimmy and Ty both contributed ideas almost equally; whenever one student made a suggestion, he would wait for the other to respond or comment on it. There was considerable debate in the team about each other’s ideas.</td>
</tr>
<tr>
<td></td>
<td>o Jimmy performed about 70% of the programming by locating the programming blocks and functions from the robotics-programming environment.</td>
</tr>
<tr>
<td></td>
<td>o Ty made the calculations for the team. He figured how many rotations it took the robot to travel the “acceleration distance” on the track. Then the two of them made some mathematical calculations, especially the relationship between wheel rotations and distance travelled.</td>
</tr>
<tr>
<td>Testing the Robot</td>
<td>This activity involved carrying the robot to the track, starting the</td>
</tr>
</tbody>
</table>
program and observing how the robot moved.
  o In team B, Jimmy carried the robot to the track and set it
down for testing. T went with him and tended to be the one
who actually followed the robot on the track and recorded
its performance in his notebook. Jimmy tended to perform
most of the physical activities, like carrying the robot to the
track and back to their workstation for them to refine their
ideas.
  o In team A, Nathalie was the one who carried the robot to
the track.

<table>
<thead>
<tr>
<th>Team discussions</th>
</tr>
</thead>
</table>
| The three activities mentioned above were punctuated by team
discussions and debates. |
| o During the introduction of the project, the students
  participated in the discussions. They talked about their
  experience with technology and what career choices they
  had made. |
| o In team C, Tom led the team discussions, just as Abigail
did in team A. He took the responsibility of making sure
  that each person contributed ideas by asking his/her
  opinion. Sally played the role of team recorder, and wrote
  down any ideas that came up in the discussions. She also
  recorded the inputs for the robots. At the track, she
  recorded how the robot moved on the track (the outputs). |
| o In team A, the students discussed together the need to
  understand the various “commands” within the robotics
  program. |
| o In team A, Abigail tended to lead the discussions; she
  asked more questions and always reminded her partner of
  what needed to be done as they worked on the tasks. |
Therefore, the student engagement in the activity varied and included engagement in the construction, programming, and testing of the robot, as well as in team discussions and debates. Engagement also varied by gender. As seen in the table 4.5, the boys tended to be the leaders of their teams. For example, in Team C, where there were two girls and a boy, Tom assumed the role of leader. In Team B, with just two students who were both boys, they were co-leaders. There were thirty-two teams in total in the eighth grade. About twenty of those were mixed-gender teams. When I observed these “mixed teams,” I noticed that the leaders were boys. This led me to draw the conclusion that gender influenced engagement in this activity.

**Teachers’ and students’ perceptions of integrated STEM instruction implementation in regular science classrooms**

The second research question for this study was “what are the teachers and student perceptions of STEM instruction implementation in regular science classrooms?” The answer to this question emerged from the analysis of the data from teachers’ and student interviews, as well as classroom observations. For this research question, I sought to determine whether or not the implementation of this new technology with science objectives benefited the teaching and learning process from the perspectives of both the teachers and students. I also wanted to learn the outcomes of this instruction from the student and teachers’ perspectives. As a result, this question focused on three main issues: instruction in the classroom; student learning as perceived by the teachers and students, and student motivation and interest in integrated STEM-based instruction. In terms of instruction, I wanted to understand how it affects student science learning and their intentions and interest in participating in STEM integration (or making connections among STEM subjects) in the future. I was also interested to know how it affected the teachers’ knowledge about teaching integrated STEM units in the science classroom in the future.
The sources of the data used to answer this research question were the student and teachers’ interview transcripts and classroom observations. In the classroom observations, I audio-recorded two student teams, and followed three other groups through their eighth grade project as they worked in their various groups. The data were then transcribed and analyzed. During each interview, the students and teachers were given the opportunity to describe their perceptions of the integrated STEM project in general, as well as their opinions on specific aspects of the projects. Then I used the constant comparative analysis of the interview transcripts (Glaser 1965) to identify student and teachers’ responses that described their perceptions and looked for emerging patterns or themes. For example, when a teacher talked about the fact that s/he believed students showed interest, I attempted to observe the students in class to identify the activities that had elicited the teacher’s positive comments.

The common themes that emerged from the data analysis are presented below.

**Teachers’ perceptions**

*Teachers believed that students showed interest in the project, learned some science concepts, and also acquired some skills during their participation in the projects*

The analysis of the teacher interview with respect to their perceptions of student interest and learning revealed that three of the four teachers believed that students showed interest in the activity.

Here are some representative examples of the statements that I coded to indicate that teachers believed the students showed interest in the activity. Steve, the eighth grade teacher, had this to say about student interest:

I was glad to see that the students were involved and creative in the way they approached the tasks. It was good to see these students show interest in the
activity and focused…Overwhelmingly, we saw a very positive response, and students enjoyed the challenge (teacher interview).

This was coded to indicate that “students showed interest because they were involved in the tasks.” Below, the sixth grade teacher, Shelley, talked about general student interest:

“I had two weeks where every single student was excited, I had to kick them out of classroom] because they didn’t want to leave, I had to hold them off at the door because they were excited to come in. So as a teacher, to see that it involved every single child, even kids that you would never imagine would be interested in this, loved it the entire time. And I can say all seventy-two of them, which was shocking to me” (teacher interview).

The teacher above was talking about students showing general interest in the activity. Analysis of the teacher interview showed that three of the four teachers mentioned that the students showed this kind of general interest in the activity. However, these teachers talked about interest in a very general way. They did not talk about the interest of individual students or teams but just addressed general interest. For example, Shelley made the following comment about student interest.

“My students showed great interest in learning the body system during this activity. They stayed focused on what they had to do during the entire project” (teacher interview).

I coded this statement as “interest in learning the science content,” which was biological content (the body system). I also coded “interest in doing the project.” However, the teacher did not say if this interest varied across students. Here is what Doris had to say about the student interest:
“The students showed interest in learning about robots: designing them, figure out ways to put pieces together in the right place, figure how to resolve what is wrong with their design. That is problem solving. They did show great interest in problem solving” (teacher interview).

This was coded as showing “interest in learning about robotics design” and “interest in problem solving.” Just like Shelley, Doris did not talk about whether the level of interest varied among the students. In the end, none of the teachers talked about variation in interest between individual students or student teams. They talked of general interest on the part of the whole class.

In my observations of the eighth grade student interest, I noticed that teachers tended to respond to all the children within a given team collectively, giving positive feedback about their interest when they noticed that a group had completed specific tasks, such as acceleration. The teacher directed comments to specific teams, not the whole class.

I observed that the teacher tended to recognize student interest during their participation in the project. This recognition consisted typically of a positive comment the teacher made each time a team of students presented their robot for testing and the robot performed the task as required (passed the test) or when the teacher came to the student workstation and observed what they were doing. For example, if the teacher observed a task where a team’s robot accelerated within the required area or made the required turn on the track and then came to a stop, the teacher tended to make a positive comment. The students appreciated these positive comments about their work. They often reacted emotionally, with expressions such as, “We got it!” or “We rock!” or “We are the best!” This reaction was a response to the teacher’s comment after testing the robot with the students. Although the students were able to recognize success when it
happened, they also required the teacher’s approval to be fully identified as success. Students also reacted emotionally for having been successful at the task. Table 4.4 shows the behaviors exhibited by a specific group or team of students that tended to get the teacher’s attention and elicited a positive comment from him/her.
Table 4.6
Student Activities that Elicited Positive Comments from the Teacher

<table>
<thead>
<tr>
<th>Student activity that elicited the positive comment</th>
<th>Positive comments from the eighth grade teacher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team A, Nathalie showed the teacher their constructed robot</td>
<td>“This is great!”</td>
</tr>
<tr>
<td>Team C tested their robot on the acceleration task</td>
<td>“I am very impressed. Excellent!”</td>
</tr>
<tr>
<td>When team A and the teacher tested the robot and it performed the positive acceleration task</td>
<td>“You guys have done an awesome job with your positive acceleration.”</td>
</tr>
<tr>
<td>When team B tested their robot with the teacher on the directional acceleration area of the track</td>
<td>“I like the fact that your robot doesn’t make a right-angled turn. Great job!”</td>
</tr>
</tbody>
</table>
Based on my observations of the eighth grade, I noticed that interest in learning about robotics, biological science concepts, and completing the tasks for the project varied across individual groups of students.

During the teacher interview, they mentioned that they believed students actually learned some concepts or skills from this activity. In their responses, I coded statements in which the teachers mentioned any science or STEM concepts that they believed the student learned. Here are some specific concepts that emerged from their responses about what students learned:

- Steve mentioned that students learned the meaning of acceleration, a physical concept
- Shelley indicated that they learned more about the human system, a biological concept

Below is a representative statement from Steve, an eighth grade teacher, which I coded to indicate that the teachers believed that the students learned some physical and biological concepts:

I think they honestly learned acceleration. Students were able to not only understand the concept of acceleration but also apply it to their robotics project…I wanted them [to] understand just the concept of acceleration, positive acceleration, negative acceleration and directional acceleration, and what they mean. I think the robotics really helped out a lot with those concepts, I really do, because when they started understanding that positive acceleration is speeding up, negative acceleration is slowing down, and you need a negative number for that, and that directional acceleration is just when you can have a constant speed, but because you change direction technically that is acceleration. So, I think they got that out of it (teacher interview).
Steve stated that the students not only learned the definitions of the concepts above, but he also emphasized that the students learned “what they mean.” Here he was talking about what these concepts mean in the context of the robotics project. This implied that learning the definition of a concept also included learning its contextual meaning. Steve spoke further about the fact that robotics “helped with this,” as “they could apply it [definition] to their robotics project.” This implied that robotics provided the students a context in which to apply the concept of acceleration that they had learned. Shelley had this to say about what the students learned:

“And so I thought it was great because they were so proud, they learned so much, including the human system and they felt so successful at the end” (teacher interview).

Here, I coded that Shelley believed the “students learned the human system which included how the systems work together, the function of each system and applied their knowledge of these systems in the project. This human system is a biological science concept.”

In the statements above, I coded, “I think they honestly learned acceleration,” and “they learned so much, including the human system,” to mean that these two teachers believed the students learned some physical and biological science concepts, respectively. These teachers’ statements suggested that these activities could help students learn more biology or physics concepts. Analysis of the data revealed that two out of the four teachers mentioned that students learned physical and biological concepts. The other two teachers did not mention any science concepts that they thought the students learned.

**Teachers believed students acquired problem-solving skills**

During the interviews, I asked the teachers if they believed that their students acquired any skills from participating in the activity. In their responses, I identified and coded statements
they made about any skills that students learned, acquired or applied during their participation in the robotics project. The first common skill that they mentioned in their responses was problem solving. I identified this because the teachers mentioned problem solving skills explicitly in their responses. Here are examples of the expressions from teachers and how I coded the problem solving skills they described:

Steve: “I think the kids acquired and applied a lot of problem solving skills in the course of the project. They worked together pretty well to figure out what to do” (teacher interview).

Here, there are two codes: “acquired” and “applied.” Thus, Steve believed that the students acquired problem solving skills and were also able to apply those skills in the robotics project. The teacher’s second statement also suggested that there is a difference between learning problem solving skills and learning to work as a member of a group. He also mentioned that they “worked together” to figure out what to do. Thus, the problem solving arose as an aspect of collaboration.

Shelley: “They acquired skills such as problem solving and working together as a team” (teacher interview).

This was coded as “learning to work together,” without a specific emphasis on this as a factor in learning. Here, Shelley does not absolutely link problem solving to teamwork. Therefore, Steve’s view of problem solving is different from Shelley’s; Steve linked problem solving to team work while Shelley did not.

Doris: “They soon learned to make decisions to put certain pieces together, not knowing for sure what the right piece was, then they get to like six steps down and it (robot) is not working, they had to figure out what to do—for them to
recognize how to resolve this design problem, they have to go back step by step backward. To me, that was problem solving” (teacher interview).

This is a version of “trial and error” as a factor in problem solving. Doris’s use of “they” indicated that she thought it was important for the students to have done this collaboratively. The results of the analysis showed that all of the teachers made similar statements, in which they indicated that the students acquired and applied problem solving skills. This suggested that:

- There is a difference between learning problem solving skills and learning problem solving skills as a member of a group.
- Students applied and acquired problems solving skills during the project.
- Trial and error is a factor in problem solving.

Teachers believed that this instructional approach (integrated STEM) will have some effect on their future teaching practice and identified areas where they will make changes

During the teacher interview, I asked them whether they believed they would use this integrated STEM teaching approach in their future teaching practice. In analyzing the data, I noticed that all the teachers mentioned explicitly that they would implement this integrated STEM approach in their future teaching. Here is what each of them had to say:

Doris: “Sure. I had already told Mario [the Technology teacher] during our little two-day workshop when I started seeing some of the sensors and the different things, I said, “My gosh, this is kind of cool.” I will be using more of it in the future” (teacher interview).

I coded this as indicating that Doris saw the potential benefit of this instructional approach and would be using it. She did not put any qualifications on her future use of the instruction.
Shelley: “Absolutely, yes” (teacher interview).

I coded this as indicating that the teacher would definitely use this instructional approach in her teaching. She also did not qualify her statement.

Steve: “Yes. It depends on the budget. With these kits, they’re expensive, totally depends on the budget I would say. You know, I think the hard part is deciding really what you want to teach” (teacher interview).

I coded this as indicating that the teacher would like to use this instruction, but that there are two considerations with respect to its use: budgetary considerations and course goals or objectives.

Mitch: “Definitely. I would always like to do it more. As a new teacher I am always looking for new methods to kind of bring the content that we set aside for seventh grade science” (teacher interview).

I coded this to mean that he would like to use this type of instruction, but it would depend on what he wanted to teach and whether he believed it was the best method to use.

Therefore, all the teachers said they would like to use this instruction in their future science teaching, but some teachers noted qualifications in using the instruction methods. One teacher mentioned that it would depend on the budget as well as the overall course goals. Another teacher mentioned that it would depend on the course content and further reflection about whether he believed that it is an instructional method that he would want to include in his future instruction.

The most experienced teachers, Doris, Shelley, and Steve (in terms of the number of years they have been teaching) view integrated STEM instruction as something that they would use in the future. One experienced teacher, Steve, put budgetary and overall course goals as
qualifications, while Mitch, the first year teacher, said it would depend on the course content and that he also needed to reflect (“I am always looking for new methods”) about whether or not to use it. Thus, the experienced teachers expressed a greater likelihood than the inexperienced teacher for future use of this method.

Furthermore, the teachers did mention aspects that they would change to ensure that the integrated STEM instruction was more effective in their science classrooms. Here are examples that emerged from the data analysis about changes or modifications that each identified:

Mitch: One thing that I have been thinking about working with different forms of technology, we are very lucky to have so many technology based tools as far as video recording, audio recording, methods that students can create and innovate. As far as the robotics kits go, I don’t know if that will come into it in multiple units, but definitely at least using the robotics’ kits and kind of working with the computer programming element at least in that astronomy unit and maybe moving it into a different unit because it can be molded to fit really any of our content areas (teacher interview).

Here, Mitch stated that he wanted to expand his use of robotics into other science topics in his class and not just limit it to Astronomy.

Doris: I will make them [robotics lessons] simpler. I think kids learn—I’ve always said that, I will do a lot of hands-on stuff with the robotics; kids learn more from doing than listening. Even if the robotics are used and we’re doing these different sensors early in the year, I can remind them of it when we get to that unit later and say, remember the ultrasonic sensor, let’s talk about how
ultrasonic sensors could be used and relate it. I do think that it’s very valuable. I don’t think I used it at its best way this time (teacher interview).

Here, I coded that Doris wanted “more hands-on activities with robotics.” She also wanted “simpler” projects. This suggests that the activity might have been too complex for her fifth graders. Also, she wants to use robotics as a method of “applying the science knowledge that students have learned.”

Steve: You know, I think the hard part is deciding really what you want to teach. Do we want to go in depth on a certain topic or do we want to cover a number of topics? Sometimes I have to prepare students for high school in some areas. Like chemistry, I really have to get them ready for the things that they get in high school because it’s so useful. And we do a lot of labs with that. On this physics unit that I do, I really—like I said, I’m open to doing a lot, I’m open to doing a lot more, maybe some open-ended stuff (teacher interview).

Shelley did not really have any specific changes in mind, but believed that he would use it in a variety of topics, especially open-ended activities.

Steve: I think that I’m going to keep with this plan for next year, but what’s going to be interesting is my students will have had a robotics unit in 5th grade, so they’ll come to me—you know, I had to start my 6th graders this year with basic knowledge and how to build the robot and how to program. This year, though—next year, my 6th graders will have had a robotics unit in 5th grade, so I’m going to have to take it further (teacher interview).

Here I coded that Shelley “would do the same thing next year, but would include more advanced activities in robotics because the students already have background knowledge of robotics.”
These statements suggested that the teachers all wanted to make changes in the instruction in the future. I also interpreted their statements to mean that this first experience did not go exactly the way some of them expected. However, they believed in its goals and the importance of its outcomes. Also, from the description of areas where they would make changes, I realized that they were not very sure about the specific things that they wanted to do. This implies that designing integrated STEM instruction needs thorough planning and that perhaps a general framework for designing and implementing integrated STEM instruction would be useful. The quality and effectiveness of integrated STEM instruction depends on its design and implementation. Therefore, teachers’ experiences could affect the way they design and implement these programs.

**Student perceptions**

**Students believed they employed the skill of persistence**

I adopted the definition of “persistence” in the Merriam Webster online dictionary: “the quality that allows someone to continue doing something or trying to do something even though it is difficult” (http://www.merriam-webster.com/dictionary/persistence). When I asked students if they acquired any skills during the activity, I used this definition to code student descriptions of any persistence skill that they believed they acquired or learned from this project. Here are representative examples of statements that I coded as persistence from Gemma’s, Trish and Leo’s responses:

Gemma: “I have learnt that you got to keep trying and not give up because there is a lot of trial and error. If [it] doesn’t work, you make changes and try and [if] it doesn’t work you try it and then it works” (student interview).
This was coded as “persistence even though trial and error was required.” Another eighth grade student had this to say:

Trish: “In our team, we made several attempts, like changing the number of rotations, the number of turns and things like that. It wasn’t easy to figure out what to do. But, we were like, we cannot give up, we have to keep going and finally [we] got [it]” (student interview).

The students used the phrase “getting it to work” or “work” to refer to the robot performing the task that it was supposed to. I coded Trish’s statement above as “persistence even though trial and error was required.”

Leo: “We have to keep on trying, and if it doesn’t work, do it again” (student interviews).

Here, I coded “persistence even though trial and error was required.” L was talking about the situation in which the robot did not perform the right task, but did something different.

During the analysis, 90% of the students interviewed made statements that I coded as indicating they “persisted” at some point in the project. Thus, I concluded that 90% of the students believed that they acquired the skill of persistence or that they learned to persist in the project. This suggested that persistence was an important skill that the students needed to learn in order to succeed in this activity.

**Students employed engineering design skills in their teams**

During the student interviews I asked them about the process that they used to complete the project. During the analysis of their descriptions of the process they used, I employed the following description of engineering design to code their descriptions for any engineering design process (EDP). According to NASA (2008), the EDP involves a series of steps that lead to the
development of a new product. These steps are: identifying the problem; identifying criteria and constraints; brainstorming possible solutions; generating ideas; exploring possibilities; selecting an approach; building a model, and refining the design (NASA, 2008); they do not have to occur in that order. I examined each team’s description and coded any steps in it using those outlined above. Here is a representative example of a team of three eighth grade student description of the process they used and how I coded it. All team members are involved in the conversation:

Lara: “We started our project by discussing in our team to make sure that we all understood what needed to be done. Then, I think we spent some time studying our robotics kit to make sure we could match the parts with the ones on the instruction sheet. Since we needed to apply acceleration, we had to discuss what acceleration is.”

Samantha added: “I did not know much about acceleration but we all understood speed and velocity.”

Lara: “We then agreed on each person’s role; mine was to be building, S was reading the instructions and Chad looked for the parts. But we helped each other, not just let one person do it.”

Chad: “Yeah. We discussed how to do everything and each person contributed ideas and then we see which one is the best idea or solution. We will then select the one that we all agreed to be the best solution. We worked as [a] team.”

Lara: “Then we build and program our robot. We had to change the power to see what happens to the robot and then we continue[d] to try different values for the power and time and kept testing our robot” (student interview).
I coded the conversation above to see if they used the EDP, as follows: when LA said, “We started our project by discussing in our team to make sure that we all understood what needed to be done,” I coded that as “identifying the problem.” When Chad said, “We discussed how to do everything and each person contributed ideas,” I coded that as “generating ideas,” and when he said, “…and then we see which one is the best idea or solution,” I coded “exploring the possibilities.” When Chad stated, “We will then select the one that we all agreed to be the best solution,” I coded “selecting an approach,” and when Lara said, “we build and program our robot,” I coded “building a model.” When she said, “We had to change the power to see what happens to the robot and then we continue to try different values for the power and time and kept testing our robot,” I coded “refining the design.” I used this coding process in each team’s descriptions and if I could identify all of the steps for engineering design in a team’s description, then I concluded that they had used an EDP. If I could not find all the steps, I concluded that they did not use an engineering design. I identified all the steps in the EDP in all three teams’ conversations. As stated earlier, Team A was composed of two girls, Team B consisted of two boys, and Team C was composed of two girls and a boy. As I observed them, I wrote down any engineering process that I saw them using. For example, in Team A, at the beginning of the project, I noted Abigail saying to Nathalie that, “we [are] supposed to construct our robot and then program it to accelerate, decelerate…” and Nathalie added, “It is also supposed to make that turn at the end of the track and stop where you have that line...” I coded this as “identifying the problem.” At the end of the observation, I had identified all the steps of EDP in what they did. I also identified similar steps in Team C. In Team B, the only step that I could not identify was “identifying the problem.” In Team B, the students did not spend any time identifying the
problem, but instead went straight to the construction of the robot. The other two teams (A and C) spent an average of ten minutes identifying the problem.

I interviewed ten other eighth grade teams and could only identify all the EDP steps in four of the ten. The remainder used a process that I could not qualify as an EDP. This suggested that for students to use the EDP, they have to be explicitly shown how to do it.

_Students believed that there was a difference between the integrated STEM approach and their regular science teaching approach _

This is one of the themes that emerged from the student interviews, in which they were asked whether they thought there was any difference between acquiring knowledge using integrated STEM projects and their regular science classes. In their responses, I coded statements that indicated that there was/was not a difference. Here is an example of a statement a student made to indicate that there was no difference.

Mary: “To me, I don’t think there was any difference” (student interview).

Ten percent of the students made similar statements. Among them, some did not really mention if there was a difference or not. They made statements such as, “I don’t know if there was any difference,” “I don’t know, I liked it.” I coded these statements to mean that there was no difference.

However, 90% of the students I interviewed mentioned that the integrated STEM approach was different from their regular science instruction. The differences that those students identified in their responses included:

- 90% said that the integrated STEM instruction was more hands-on than their traditional science instruction. One representative student statement was:
Abigail: “I like this project more than my science class because it was more hands-on” (student interview).

- 85% said that in integrated STEM, they were responsible for their own learning and were not told what to do, as in most of their science classes. Several representative student statements were:

  Thomas: “Well, he didn’t really tell us anything about it. We just went ahead and did it ourselves. We can kind of mess along the way and then fixed it.”

  Carol: “Yeah. He (the teacher) just told us a few definitions and that was it.”

  Gemma: “Instead of being lectured to, you can find it out for yourself and I think that may involve some students more because some people don’t like being talked at, they like being able to do it by themselves” (student interview).

This suggests that students believed that the integrated STEM instruction is in some ways different from their traditional science instruction because the teacher allowed them to learn on their own, he did not lecture to them, and they had to figure out the meaning of concepts by themselves.

*Students perceived the teachers’ instructional approach, and the nature of the integrated STEM activities as motivating factors for learning, engagement and interest in the robotics activities*

The analysis of eighth grade student interviews suggested that most students were motivated by and interested in the project at some point. This was deduced from the student discussions about their attitudes towards the project. In the analysis of the student interviews, they often mentioned as the aspects that motivated them (which I coded as the motivating factor) the nature of the activities or project and the teaching approach (the way the instruction was
implemented) that their science teacher employed. In the analysis, I separated these into two factors, although in some cases students mentioned them together, as will be seen later in some representative statements that emerged from the analysis. Here are the attributes of the teaching approach that the various teachers said that they used.
Table 4.7

*The Instructional Approach that Various Teachers Used and How Students Viewed it as a Motivating Factor*

<table>
<thead>
<tr>
<th>Grade</th>
<th>Attributes</th>
<th>Student perceived motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Five</td>
<td>o Placed students in teams</td>
<td>I did not observe the class and did not interview students</td>
</tr>
<tr>
<td></td>
<td>o Students work on their own, with limited teacher intervention (telling them what to do)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o No lecturing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Students planned how to design their robot. They solved problems they came across while designing the project</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Students had to figure out ways to design their robots. There was no predetermined solution. Students determined and managed information from the EV3 construction guide</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Students had to always reflect on what they were working on</td>
<td></td>
</tr>
<tr>
<td>Six</td>
<td>o Placed students in teams</td>
<td>Did not interview students</td>
</tr>
<tr>
<td></td>
<td>o They worked on the “body forward” project, which is relevant to their own lives. The students had to design the robot on their own and use it to perform tasks (such as repairing a broken bone)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o The teacher defined the goals of the project and the tasks that they needed to complete clearly. She also gave them the assessment rubric</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o The teacher stepped back and allowed the students to do the work on their own. No lecturing</td>
<td></td>
</tr>
<tr>
<td>Seven</td>
<td>o The teacher placed students in groups</td>
<td>I did not observe the class and did not interview students</td>
</tr>
<tr>
<td></td>
<td>o The students worked on the “asteroid exploration project”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o The teacher made the goals of the project explicit to the students and let them work on their own to discover the solution to the task</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o He asked the students to assess each other (peer assessment)</td>
<td></td>
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</table>
The teacher started the project by introducing robotics and the students were involved in some discussions about programming.

- He showed them a sample robot that he constructed.
- The teacher assigned the students to teams, and distributed the EV3 kit and assessment rubrics.
- He stated the goals of the project and the various tasks that the students had to complete as a team clearly.
- The teacher allowed the students to develop their own plan to complete the task.
- He assisted students in answering questions about the project. He interacted with students, providing clues and asking them open-ended questions that stimulated them to think critically.
- He provided students with immediate feedback on whether or not their robots completed the acceleration tasks and offered students clues on how to modify their inputs.

I observed the class, and interviewed students and the teacher.

- Students felt motivated by the fact that the teacher allowed them to work on their own. No lecturing.
- They felt motivated by the fact that the teacher was there when they needed him to answer their questions.
- They felt motivated by the fact that the teacher chose an activity that enabled them to use a more hands-on approach to learning.
Here is a representative statement from the eighth grade student interviews about how the nature of the activity and teaching approach emerged as motivating factors in the student statements. Emma had this to say:

“In our group we were very serious because we could tell if our robot could perform the task or not by ourselves. We all like[d] that because you did not have to wait for the teacher to tell you, we were just like…what we have done is not good so let’s go back and check. That was fun to do even. Everyone was contributing ideas and nobody wanted to go home without getting our robot to complete at least the negative acceleration part today. We finally got it! Yesterday, we were able to complete the positive acceleration and we learned a lot from it. That also motivated us in our group to keep working hard to accomplish the task” (Student Interviews).

In this comment, I coded “the immediate feedback from the robots’ performance,” and, “the students have a clear understanding of what they were supposed to do” as the motivating factors. These two factors were attributed to the nature of the activity and the teacher’s instructional approach, respectively. Another student, Mary, stated:

“We were all determined in our group to get everything done. Our teacher has told us what we were expected to do, like the acceleration and the positive acceleration. My teammate and I worked together very well; we tried to figure stuff out on our own. We were motivated because we had to do it on our own and we could test to see if our ideas were right. We wanted to make sure that we completed the whole task and I am glad we finally got everything done. We never give up and that is great” (student interview).
There were two codes in the statement above: “the students knew what the teacher expected them to do,” “they worked on their own to discover the solutions,” and “they were able to get immediate feedback by testing their robot.” These are motivating factors that were attributed to the teacher’s instructional approach (“the students knew what the teacher expected them to do,” “they worked on their own”) and the nature of the activity (“they were able to get immediate feedback by testing their robot”). These student statements also suggested that they were not simply motivated, but were determined to complete the task. Bruner (2004) posited that when students work together to discover their own solutions, they tend to remember what was taught. Bruner defined this as discovery learning. Based on Bruner’s (2004) suggestion, I coded that there was discovery learning in Mary’s team.

As I analyzed student interviews, they mentioned the following attributes of the instructional approach and the nature of the activity as motivating factors. In terms of the instructional approach, the students that I interviewed mentioned the following attributes:

- The teacher allowed them to work on their own
- The teacher placed them in teams and they worked together to come up with own solutions. Each teammate was equally accountable for the success of the project
- The sample robot that the teacher showed them at the beginning of the project raised their curiosity and motivated them to achieve something similar

With regard to the nature of the activity, I extracted the following from the student interviews as motivating factors:

- The fact that they could test their robot and get immediate feedback or see the results of what they have done in real time. They viewed this as something that motivated them to take control of their own learning. Feedback was an important aspect of this project,
because as I observed in the eighth grade, students would literally stop working and wait to receive feedback from the teacher. In the three groups that I followed, I observed that in each session, a team did this five times on average

- They had the flexibility to work on any task (except for the construction of the robot, which was the beginning point for all students)

Analysis of student interviews showed that 60% mentioned the instructional approach (at least one of the attributes from the list above) and the nature of the activity (at least one of the attributes from the list above) as motivating factors. Thus, 60% of the students were motivated by the instructional approach and the nature of the activity. The remainder of the students mentioned either the instructional approach or the nature of the activity. What I noticed was that each student that I interviewed cited at least one motivating factor—either the nature of the activity and the instructional approach—or one of him or her.

**Challenges that teachers Encountered during integrated STEM instruction**

During the teacher interview, I asked about challenges that they encountered with the instruction. By challenges I meant anything that hindered implementation or prevented the teacher from meeting his/her intended lesson objectives. Analysis of the teachers’ responses revealed that all of the teachers mentioned that they faced one or more challenges during the implementation of the project. Here are the challenges that emerged from the analysis of the interviews:

*Teachers lacked technology and engineering content knowledge*

During the analysis, the first challenge that teachers mentioned in the interviews was their own lack of technology and engineering content knowledge. They all were trained in science education, but said they did not have any technology or engineering education training. All of
these teachers also indicated that they relied on the technology teacher for support on how to help students with technology content knowledge, such as helping them with questions about how to download the robotics program, how to answer questions about coding, and troubleshooting problems with their robots. For example, Doris, the fifth grade teacher, mentioned that her students never programmed the robot because the technology teacher was not available to help them the day she had planned to perform the programming. As a result, she did not conduct the programming with the students because she “did not know anything about programming.” Here is what she had to say:

“My support person[’s] (“my support person” here is the same as “the technology teacher” and not an aide) schedule did not allow him to be in my classroom as a support for me all the time. That made it even more uncomfortable and awkward for me. There were questions I couldn’t answer. The day that some of the kids were ready to do computer programming, but I wasn’t prepared...I did not know anything about programming. I am not the knowledgeable one there. I had to make a decision about not programming because I knew nothing else to do” (teacher interview).

This statement suggested that without the proper content knowledge, the teachers would be unable to assist their students if they had problems that required an understanding of technology. In addition, all of these science teachers mentioned that they not only had to collaborate with the technology teacher, but also relied on him heavily because he had the necessary technological and engineering knowledge for the robotics project. Here are some representative statements from the fifth, sixth, seventh and eighth grade teachers, respectively, that emerged from the data analysis:
Doris: “I did not know anything about robotics. Mario (the Technology teacher) was my advisor, so to speak, and he was the one I went to when I found out I had to incorporate robotics into my classroom” (teacher interview).

Doris: “Collaboration with Mario was necessary. He came to most of my classes and he was there to support because I didn’t have that much knowledge of the actual robotics kits. He helped with support when the kids were struggling with parts and different aspects of building the robots.” (teacher interview).

Shelley: “There was a lot of collaboration with Mario because he certainly has the most knowledge, so he was my ‘go to’ for questions on logistics, how to do it.”

Steve: The couple of problems that I had were when the kids would ask me about coding; I didn’t know some of the answers, and if Mario wasn’t around that was really sort of tough (teacher interview).

Mitch: One challenge would definitely be just my limited knowledge working with the technology. He [Mario] was instrumental in working with me in the classroom. He had a lot of hands-on assistance in the classrooms (teacher interview).

These quotes suggest that these teachers would have been more effective in the implementation of the integrated STEM instruction if they had the necessary STEM content knowledge and training, especially the technology knowledge that was much needed in this activity. It also speaks to the fact that the technology teacher was essential for the success of these lessons.
Another challenge that emerged from the analysis of the teacher interview was lack of sufficient time for lesson preparation and instruction. Three of the four teachers mentioned during the interviews that there was not enough time for them to plan and implement the instruction in their science classrooms. They stated that they needed additional time (than what they take to plan their normal science instruction) to plan and implement the integrated STEM instruction. In planning, they spent more time searching for robotics activities that would fit into their science objectives without extending the class period. In implementation, they needed more time during the lessons, because it took them longer to assist students with technology-related questions. For example, Doris mentioned that she never completed the programming part of the project in her class because they (she and her students) spent too much time building the robot.

Here is a representative statement that emerged from the data analysis, which I coded to indicate that there was insufficient time for implementation. The fifth grade teacher had this to say:

“I know about robotics now…we spent the entire two weeks on building the color sorter. Therefore, I didn’t really get the time to actually help them understand how the light sensor works other than just saying it is designed to get a percentage of the amount of light that’s being reflected.”

Shelley, the sixth-grade teacher had this say:

“The biggest challenge was how to make it work time-wise. I did not have enough time to plan and implement the project in my class” (teacher interview).

These statements suggest the importance of making sure that there is enough time for teachers to plan and implement the activity in the science classroom. However, during the analysis of the
interviews, I also noticed that Steve, the eighth grade teacher, stated explicitly that he did not have any problem with time:

“Time-wise I think we worked well. Time-wise I think things worked really well with this project. I felt like we hit at about the right amount of time” (Teacher interview).

My interpretation here is that, unlike the lack of technology content knowledge, which was a problem common to all of the teachers, not all of them had a problem with the time needed to implement the instruction. Steve’s statement above meant that the time required matched to what he had planned for or expected prior to the start. This is different from what Doris said about time. Doris mentioned that the required did not match to what she had planned for or expected prior to the start. Shelley had the same opinion about time like Steve. I realized that the teachers who were the most easily able to do the robotics (knowledge of the robotics unit) also had the fewest concerns with time. Therefore, I deduced that the time for implementing an integrated STEM instruction depends on the teachers’ content knowledge of the instruction unit and the support they receive during the instruction. With a good content knowledge, they are able to align the integrated activity with the science objectives; else they will spend much time during the implementation trying to figure out how to align it.

**Teachers faced the difficulty of incorporating the robotics project (integrated STEM-based project) into the science curriculum on their own**

Another barrier that emerged from the analysis of the teacher interview was how to incorporate the robotics project (integrated STEM-based project) into the science curriculum. Their regular middle science curriculum does not include integrated STEM standards or projects. In addition, the *Lego Mindstorms* does not provide directions on how to integrate its robotics
project into a science curriculum. The problem that emerged from the data analysis was that these teachers not only lacked the technology content knowledge, but also did not have any significant previous experience incorporating robotics or similar integrated STEM projects with their science curriculum that might have helped them with this particular instruction. During the interviews, only one of the four science teachers mentioned that she had some prior experience with robotics, although her experience was not with integrating robotics into the science classroom, but as a coach of the robotics club in the school. However, the robotics club did not relate their activities explicitly to the science standards or objectives. A coach might know about the activities, but would still have to determine how to incorporate them into his/her science standards. None of these teachers indicated that they had ever used robotics in their science lessons. They mentioned during the interviews that they had difficulty deciding how to incorporate the activity into the science curriculum in order to help students connect the concepts from the project to the science and other STEM domains. Here are representative statements from three of the teachers about the challenge of not being able to integrate the project into the science standards.

Doris: “I recognized that it didn’t support my science unit of light the way I thought it would, because I clearly didn’t have a true understanding of the project itself.”

Shelley: “The biggest challenge was how to incorporate the activity into the science curriculum.”

Mitch: “Well, my first unit of the year was based on astronomy and so in working with [the technology teacher], we had to incorporate [the] activity into my science curriculum, specifically in the unit of the solar system” (teacher interview).
These statements suggested that aligning integrated STEM activity with the science objectives is an area with which teachers will need help. The teachers explained further that they wanted a project that could be integrated with their science curriculum, specifically with the topics that they were teaching at the time. In addition, they wanted a project that they could have used to help students learn the science concepts, or to enhance their conceptual understanding of science, as well as help them apply those science concepts in real life situations—or preferably all three.

In this section, I have presented the findings related to teachers’ and student perceptions of integrated STEM instruction. Most of the students believed that their teacher’s instructional approach and the nature of the integrated STEM activities were the motivating factors for their learning, engagement and interest. Most of the teachers believed that the activities enhanced student interest and motivation. Three out of the four science teachers and most of the students believed that integrated STEM instruction helped the students acquire and apply such skills as problem solving. They further believed that integrated STEM projects enabled students to use competencies such as persistence, engineering design, and analyzing and interpreting data. The teachers also appreciated the fact that most of the eighth grade students thought the activities were fun even though a few students preferred this instructional approach to their regular science instruction. Teachers believed that the integrated STEM approach would have some effect on their future teaching practices. Finally, another theme that emerged from the teacher interview was the barriers or challenges that they believed they encountered in the course of the implementation process These barriers included lack of sufficient time to implement the instruction, lack of content knowledge and difficulty in aligning the activity with the science objectives.
Overview of the findings

Analysis of the teacher interview, classroom observations and student interviews revealed that in order to effectively implement integrated STEM education in the science classroom, the teachers needed to possess the necessary STEM content knowledge. In the absence of this knowledge, a reliance on the technology teacher became essential to the effective integration of this new curriculum. The teachers also wanted an integrated STEM project that was aligned with their science curriculum. Further, each teacher had certain expected outcomes of such instruction and most of them assessed these outcomes.

Analysis of the student interviews and classroom observations indicated that the student perceptions could provide valuable insights about how to design these integrated STEM activities in a way that would benefit their learning. Students and teachers viewed these projects as engaging. Some students even believed they helped them understand the science concepts better than did their traditional science classes. As far as the teachers were concerned, I do believe that effective integrated STEM instruction involves more than preparing a lesson plan. It is an entire process, which, based on the results of the data analysis, I have referred to as an implementation process. The components of this process are interrelated and it all begins with teacher professional development, especially in areas of STEM content the teachers’ lack. Theoretically, the training would enable the teachers to gain some knowledge about how to develop an integrated STEM instruction that is incorporated effectively with the science standards. Figure 4.3 shows an outline of the implementation process that the teachers in this research study undertook. In this figure, there are two stages: preparation and implementation. These stages constitute the implementation process. The implementation includes support that the teachers provide to help the students, as well as the implementation and assessment. The
implementation process that emerged from the data is summarized in Figure 4.3. The figure shows the various phases and the categories within each phase. This figure shows the temporal arrangement of the events within the implementation.

I observed that the implementation process at this school began with preparation, in which the science teachers attended a two-day workshop organized and sponsored by the school administration. The workshop focused on introducing the teachers to the Lego Mindstorms NXT robotics kit. For example, in the eighth grade, the workshop included instructions on how to build a robot using the kit provided, and how to program it to perform different tasks (e.g., detecting an obstacle in its path, moving in a specified direction at a specified speed).

Another part of the preparation that emerged from the data analysis was the collaboration between the science teachers and the technology teacher. This collaboration was very important, as it affected how they worked together to determine which projects to use in the science classrooms, the subject matter objectives to emphasize, and the support required to deal with the technology content knowledge that the science teachers lacked. The selection of the specific student project implemented in the classroom resulted from discussions and examinations of course goals that took place between the technology and science teachers of each middle school grade.

During the observations, I noticed that the eighth grade teacher provided any necessary support to his students. For example, he came to Team C and helped them find a missing piece from the kit during the robot construction. He also answered questions from this team about which port to use to plug in the sensor, how to save their work and to recover saved files. I also noticed that during the project, Team C students who needed the teacher’s feedback would literally stop working to wait and receive feedback from the teacher when he was busy helping
other students (Team A did this on average five times per class session). This happened at least sixteen times in each session in the eighth grade. To me, this underscored the importance that students placed on getting the project completed and the need for the teacher to be accessible to them at all times during the project. Therefore, for the implementation to be effective, the teacher would need to have a mastery of the technology content so that s/he would be ready to answer student questions in a timely manner.
Figure 4.2. The implementation process
Results from the student interviews showed that integrated STEM instruction enabled some students to make connections between different concepts from STEM disciplines, as shown in Equations 1, 2 and 3. This enhanced the student awareness of the connections between different content areas, such as those between mathematics, science and technology. As discussed earlier, most students were motivated. This integrated STEM instruction was student-centered and afforded the students the opportunity to work collaboratively. Teachers also acknowledged that they would make some changes to their future teaching practice based on this experience. However, some challenges that affected teacher effectiveness and self-efficacy was their insufficient knowledge of the content in the STEM subjects being integrated and how to incorporate the projects into their science standards.

**The Theory that Emerged from this Study**

When I embarked on this study of integrated STEM education, I wanted to find out how teachers implemented this approach in their existing science classrooms so that other teachers could use the strategies that influenced successful outcomes. This process has not been examined before. Therefore, I had a strong motivation to determine how the teachers implemented the instruction. It was appropriate to use Grounded Theory to construct what happened (challenges and approaches they used and the student perspectives about the instruction). According to Stein (1980), the foundations of Grounded Theory require the investigator to look for processes that are taking place in the social scene. Thus, I observed the teacher-student and student-student interactions to capture those processes, such as team discussions of the approach or plan to be used in the project, and the various student activities that elicited positive comments from the teacher. For those classes that I did not observe, I used the teacher interview as a means to understand the process. Some perceptions of the challenges that they had to overcome caused
them to approach the instruction in a particular way, or their dependence on the technology teacher influenced their instruction in a particular way. For example, the fifth grade teacher could not accomplish programming in her class because of her lack of robotics knowledge.

As I analyzed the data in this study, I arrived at the supposition that the collective knowledge of all the teachers present for a given instructional session (in this case the technology teacher was present much of the time) is essential for the success of the integrated STEM instruction. The technology teacher was an essential presence some of the time in these lessons. So, what I found was that it is not the knowledge of the science teachers themselves with regard to the robotics unit that is essential, it is the collective knowledge of all the teachers present. And in this case, the technology teacher had to be present because the other teachers (science teachers) technology knowledge was so low. Thus, the theory here is that there is a total amount of knowledge needed for effective implementation and if the teachers themselves don’t have it, then it has to be supplemented. The source of supplementing it, in this case, was the technology teacher coming in. But, there are other potential sources of supplement such as technology resources, Internet such as YouTube videos, books, and professional development workshops.

The motivation for this STEM activity arose outside of the teachers’. The school administration supplied the directive or motivation for this instruction. There was an apparent recognition that the technology teacher was to be an essential component of the integrated STEM unit as he was part of the directive from the conception of the idea. And thus it was recognized by the school administration that there was a total amount of teacher knowledge needed for the effective implementation of this particular integrated STEM instruction, which prominently featured robotics.
The results of this study suggest that this total knowledge needed for successful implementation could be internal or external to the teacher. Taken as a whole the teachers need to have knowledge of:

- Appropriate pedagogy such as project-based and hands-on learning
- The technology that is to be integrated into the science lessons which in this case was robotics and certain subunits under robotics such as programming
- Students’ abilities so that they can scale the activities to the right level for the students to be able to do it.
- Aligning the project to the science objectives and therefore knowledge of appropriate assessment methods to evaluate the students’ accomplishment of those objectives.

All of the knowledge described above need to be available for enactment in an instructional situation regardless of whether the knowledge resources are internal or external.

If resources are external, they must be supplied by others within the teacher’s access. These individuals might include:

- The technology teacher;
- Extra (outside of) school person with expertise such as the engineering graduate who came in to help the eighth grade teacher;
- Internet-based resources like YouTube videos;
- Traditional resources like books; or
- Professional development activities.

Figure 4.4 summaries the total teacher knowledge needed for the effective implementation of integrated STEM instruction.
Figure 4.3. The summary of the total amount of teacher knowledge needed for integrated STEM instruction.
In this study, the teachers did not possess all the internal knowledge described above; they lacked the technology knowledge specifically with regard to using robotics in the classroom as a component of their science instruction, and the ability to align the activity with the science objectives. However, the implementation generally had a satisfactory enactment because of the presence of the technology teacher as a source of external knowledge. His absence in fifth grade led to unsatisfactory results as indicated by Doris, the fifth grade science teacher. Therefore, I propose the theoretical statement that the total level of teacher resources whether held individually or collectively must equal to some criterion level of teacher knowledge. Consequently, the more proficient a teacher is in the total forms of STEM content knowledge needed for that instructional segment, the more effective their implementation of integrated STEM instruction. If the teachers are not proficient in the total forms of STEM content knowledge, external resources (as described above) are needed to support them.

This theory was derived from the fact that all the teachers in this study admitted that their lack of technology content knowledge or robotics knowledge was a major challenge. They all possessed sufficient science content knowledge, but not technology knowledge, which in this study was specifically knowledge of the instructional use of robotics. Because this was integrated instruction that involved science and technology (robotics), they collaborated with Mario, the technology teacher, because he possessed the technology knowledge needed. As a result, they all depended on the teacher who had more experience in the subject matter. In the seventh grade, for example, the teacher mentioned that she could not perform programming with her students because the technology teacher was absent and she said: “I had no knowledge, so I had open arms—whatever you [referring to Mario] could help me do I would love it” (teacher interview). This was an indication of her total dependence on his help. His absence from that class changed
the entire instruction, as the science teacher could not proceed because of her lack of the programming knowledge necessary. As a result, she did not assess the student learning and was disappointed with the entire instruction. This was not the case in the other classes, where Mario was there to assist them. These teachers were more confident in implementing the instruction because they knew that he was available to help. They also assessed the student learning. Thus, the success of the implementation revolved around a single person. If he had not been part of the team, the school administration would have never tried to push for the implementation of the integrated STEM activity.

Summary

In this chapter, I examined the actual implementation process that the teachers used to incorporate technology and science objectives in science classrooms using robotics equipment. The evidence presented here supports the contention that integrated STEM instruction could benefit student learning, as well as STEM teaching. However, science teachers who do not have experience with this type of instruction faced challenges, including lack of content knowledge in the other STEM subjects and difficulty linking integrated STEM projects with the science standards and time constraints. These challenges were met by the presence of Mario during the implementation. I have also discussed the major findings in the “Over of findings” section. Students benefited greatly from this experience, as most of them viewed the project as a way to keep them engaged, motivated, and “owners” of their knowledge construction. Based on the findings of this study and on the literature of integrated STEM education that I have spent some time perusing, I deduced that the implementation of integrated STEM instruction actually followed a procedure. As a result, I proposed an integrated STEM framework (IntSTEM) that will be discussed in Chapter five, which provides guidance on how to go about implementing
integrated STEM instruction in the classroom. In the next chapter, I will also discuss the major lessons learned from these findings and provide implications for science teaching and student learning.
CHAPTER 5
DISCUSSION AND IMPLICATIONS

In this chapter, I will discuss the key things that I learned from this study. I will also discuss the contributions of this study to the STEM education literature, and the implications of the findings for K-12 STEM teaching practice and student learning. I will also present a proposed integrated STEM framework, IntSTEM framework, which could be used to guide teachers in the design and implementation of integrated STEM instruction. Finally, I will discuss the implications of the findings for future research.

Nature and sources of integrated STEM based projects and its infusion into the science curriculum

The first lesson that I learned from this study was the fact that all of the approaches the teachers employed to introduce a robotics unit into a regular science course were project-based and hands-on. The projects included tasks or problems to be solved by the students. The project involved authentic and potentially real-life problems. These problems required that students apply science knowledge, engineering design practice, and problem solving to resolve them. This implies that an important feature in the implementation of integrated STEM instruction is the design of the project that the students will be presented with. This is crucial because a poorly designed project would definitely not achieve the intended purpose of the instructional unit and will leave teachers dissatisfied. Most teachers will need help in designing or selecting a suitable project for their classes, especially if they are not trained in the other STEM content knowledge involved in the project. The selected project has to contain certain features like involving at least
two STEM disciplines with well-stated objectives. I also realized that the instruction was problem-based and student centered. The problem to be solved promoted higher order thinking, was complex, ill structured and open-ended, and promoted motivation among students, which support (Hmelo-Silver, 2004) description of the nature of problems in problem-based learning. Integration thus requires that the teachers examine the curriculum and understand which science concepts might be (or are to be) addressed by a chosen or designed project and make the necessary curricular modifications. In this research study for example, the EV3 kit was already there for the teachers to use, so, they had to design or look for projects that involved this kit and relate the projects to their science standards. However, it wasn’t easy for them to select the project and infuse them into the science curriculum. Some resources of integrated STEM projects are available to serve as the starting point for teachers with no prior knowledge on integrated STEM instruction. These resources may be in the form of curricula that can then be modified to better suit the teacher intended lesson objectives.

Implementation has to balance learning in the individual STEM subjects. This can be accomplished by finding more connected ways of learning in STEM in general. This is just one approach, there might be others where the students learn the science concepts as they do the STEM activity. I learned from students and teachers interviews that the student conception of science and technology knowledge resulted from their sustained engagement, persistence and collaboration in the process of constructing knowledge. This knowledge construction occurred through various social negotiations like brainstorming, questioning, explaining, receiving timely feedback and examining ideas in their various groups. Students worked in teams and listened to the ideas of their teammates, refined their own ideas and helped the group solve the task at hand. Through these collaborative social exchanges or interactions, students were able to construct
their own personal knowledge of the project as discussed in the interviews. It was clear that the approach that the teachers used here was a constructivist-based approach because it put the students’ own desire and efforts to understand at the center of the entire instruction. Therefore, in designing integrated STEM instruction approach, think of the constructivist-learning environment, which enhances collaborative knowledge building (Jonassen, 1991).

**Linking integrated STEM projects like robotics project to science instruction and the teaching approach used.**

Integrated STEM education proponents expect teachers to teach in an integrated manner. But, it is not an easy task to design instruction that is integrated. This demands extended lesson planning, and as stated previously, starting with selection of suitable projects. In this research study, teachers infused the robotics project into their science standards by making sure that the activity supports or helps students to understand and apply scientific concepts and also learned some concepts or skills from other STEM domains. For example, in the eighth grade students mentioned that they applied the concept of acceleration and learned programming or coding. This was done by first identifying the specific science concepts and then incorporating them into the robotics activities. For example, in the eighth grade, the main science concept was acceleration and the teacher wanted the students to understand and apply their understanding of acceleration as they design and program their robots, rather than just program the robots. Across the grades, the teachers each had their objectives and communicated them to the students. They made efforts to link any assessment to their science standards and other twenty-first century competencies like working collaboratively and problem solving. The implication of this is that for teachers to effectively implement integrated STEM-based projects in their science classroom, they have to be able to explicitly map the science concepts to the projects. Else, some teachers
will end up dissatisfied and discouraged as was shown by Doris in this project. Consequently, they will become resistant to such integrated STEM instruction.

Another important take home lesson for me was the constructivist approach that the teachers used to afford students with the opportunities for participation and engaging in learning. The science teachers were not dominant in the classroom but rather gave more authority to the students to develop their own understanding of the concepts. Teachers attempted to emphasize integration between STEM subjects. However, given the situation the teachers found themselves in, they used the technology teacher to supplement their lack of knowledge and competency about how to do integrated STEM teaching

As an educator, I believe that when other teachers in the same school come to realize that students actually learned some STEM concepts and acquire some needed skills from designing these robots then they will be more willing to try similar projects in their classrooms. The results of this research provided support that student learning was enhanced as the sixth and eighth grade teachers mentioned that students learned some science concepts like acceleration and the functions of the human system. Students were also engaged, which should encourage teachers to find ways infuse similar integrated STEM modules across a range of sciences and other STEM disciplines.

**Students’ learning is enhanced by Integrated STEM instruction**

The learner needs motivation, skill and environment for change to achieve competence in any given area (Ford, 1992). With the active learning involved in these projects, the students took significant control over the learning process. The data analysis results of students’ interviews, classroom observations and teachers interviews showed that the projects, which were also problem-based in nature and involved active learning, motivated students to learn. Students
expressed their satisfaction with their learning in these projects because they were able to see how their ideas could be put to use and received immediate feedback both from the teacher and by testing their robot. When the students in eighth grade for example, tested their robot on the pathway, they received immediate and real time feedback from the teacher and from testing their robot. Immediate feedback clearly motivated some of them. During a class observation, I asked a group of students why they were so jubilant and the response was “We just got our robot to accelerate and decelerate!” This was because they had tested their robot and realized it did what they wanted it to do.

Hence, in this study motivation and task accomplishment were important outcomes of the integrated STEM instruction. However, most of the teachers assessed the outcomes of student performances with reference to content knowledge gains, which is done in a more formal testing situation. Thus the teachers viewed outcomes of formal assessment as an important part of the instruction. The eighth and sixth grade teachers also mentioned during the interviews that the instruction actually helped students learned science concepts such as acceleration (for eighth grade) and the human system (in the sixth grade).

Teachers used a variety of different forms of assessments in the integrated STEM instruction

In any instructional design, the teacher has the responsibility of being accountable to student learning based on student outcomes (Kuskie & Kuskie, 1994). In this research study, I learned from data analysis of teacher interview and classroom observations of sixth and eighth grades that teachers attached a lot of importance to assessment. Though these teachers were not experienced in the area of integrated STEM education, most of them still made the effort to include an assessment in their instruction. I learned from the teachers’ interviews and classroom
observations that they used varied assessment approaches like rubrics (sixth grade), peer assessment (sixth, eighth and seventh grades), and performance assessment (sixth, seventh and eighth grades) and informal assessment (eighth grade). However, since most integrated STEM instruction goals are also focused on providing students with some lifelong skills like problem solving, data analysis of classroom observations showed that the teachers like the eighth teacher paid more attention on how the students work (the process) than on the product. For example, Steve, the eighth grade teacher, designed assessments that required students to assess the performance of the peers during the entire activity. This is because these teachers believed that in the process of completing the project, the students learned or applied skills like problem solving, and persistence, which would otherwise not be recognized if the assessment were focused on just the end product. For example, the eighth grade teacher awarded points for intermediate achievements such that a student could still obtain a good grade without completing the activity. Also, the teacher employed multiple assessment methods. For example, there were peer assessments, rubrics and performance assessments. What this implies in integrated STEM instruction is that when designing this type of instruction, it would be helpful to incorporate multiple assessments in order to capture student achievements. It is important to understand that since integrated STEM instruction draws objectives from two or more STEM disciplines, the assessment has to reflect all of these objectives (for instance, in the eighth grade in this study it should support conceptual understanding of acceleration and programming).

In my view, assessment of the process is important because not all cognitive process and all aspects of learning can be captured by summative assessment. The students in the study only showed their understanding through what they did and did not express their thoughts to the teacher in order to be awarded credit. It is therefore helpful to use prompts during continuous
assessment to stimulate these students to express their thoughts and their understanding and find ways to assess these thoughts. This assessment of the process also fosters a continuing developmental discourse between the instructor and the students. Acquiring knowledge is an accumulation and association of components of skills (Greeno et al. 1996).

**Benefits of integrated STEM instruction in the classroom**

In this study, I learned from the findings that there are some cognitive benefits of integrated STEM education to students. Student interview analysis revealed that most of students acknowledged that the robotics activity enhanced skills like problem solving, and working collaboratively. In addition, data analysis of classroom observations showed that the robotics activities support students to apply STEM concepts involved in the projects. These projects offered students context in which they could use to apply their developed STEM conceptual understanding. This supports the claim that technology based projects like the integrated STEM robotics project are used to offer a setting or context in which students could use to apply their developed STEM understanding (Lewis, 2006; Venville et al., 2004). This integrated STEM robotics project also provided students with a constructivist-learning context to build their own understanding of the underlying STEM concepts in the projects. Data analysis of teacher interviews showed that activities that were chosen involved at least two STEM disciplines, were based on real life context and constructivist in nature. Thus, unlike traditional instruction where students are taught in a compartmentalized manner, integrated STEM instruction emphasizes the integrated nature of real life tasks (Breiner et al., 2012). Breiner et al., (2012) stated “viewing the separate disciplines of science, technology, engineering and mathematics as one unit, thus teaching the integrated disciplines as one cohesive entity.” (p.5).
Students constructed their own understanding of the concepts involved and applied the knowledge rather than memorizing facts. Student understanding of science concepts was enhanced by these activities. The inclusive and hands-on nature of the activities enabled students with various experiences to contribute and be part of the learning process. Integrated STEM activities enhanced active learning and knowledge construction, which supports the claim that integrative STEM education pedagogy is fundamentally learner-centered and knowledge-centered (Bransford, Brown, & Cocking, 2000). Thus can also provide a conducive environment for social interaction among groups of learners. This social interaction is essential for the learning process (Sanders, 2009).

These findings also showed that the students exhibited their willingness and determination to spend more time beyond class time working on the projects. Many of them went as far as asking the teacher if they could stayed longer or come and work on the projects during their spare time. This is evident of the interest and motivation of integrated STEM activities and falls in line with Skinner and Belmont’s (1994) claim that highly motivated students are enthusiastic, interested, involved, and curious (p.571). These researchers further contended that highly motivated students want “to stay in school longer, learn more and feel better about themselves” (p.571). Therefore, using integrated STEM activities could help optimize student motivation since it is difficult to optimize student motivation (Skinner & Belmont 1994, p.571). The science teachers in this study were very impressed in the amount of interest their students showed in this integrated STEM instruction. Though the teachers started off with some resistance and lack of confidence, they ended with enthusiasm and determination to continue using this type of instruction. They viewed it as a teaching method that helped students develop an
understanding of STEM concepts and practices and make the connections between and among STEM concepts.

With the constructivist nature of the robotics activities, students were able to exert more control over their learning. When they facilitated their own learning, they created a distinctive set of their own conceptual depictions grounded on their personal experiences (Jonassen, Peck and Wilson, 1999). The integration of STEM is done using tasks like robotics that are applicable to the real world. These tasks are focused on inquiry and therefore assist with higher order learning. They help students with knowledge development, synthesis and application. Thus, it may be helpful for teachers who want their students to be more engaged, construct their own understanding of STEM concepts and develop certain skills at the same time to include integrated STEM projects in their science curriculum. Activities like robotics are not new in schools. What makes them different is how they could be used in the science classroom to enhance the understanding of science concepts and get students more engaged. However, the teacher will have to infuse them into the science curriculum in a way that meets his or her expected outcomes.

This study was developed based on the assumption that teaching is a very complex cognitive activity that requires the teacher to draw knowledge from multiple sources and knowledge domains. In addition, teachers’ philosophical beliefs influence their pedagogical approaches (Kanuka, Smith & Kelland, 2013). Within this assumption, the idea underlying this study is that integrated science, technology, engineering and mathematics (STEM) instruction serves as a source of knowledge and teaching approach that impacts teaching practice in STEM education and help students make connections between and among STEM concepts. This connection then leads to relevant and meaningful learning. Integrated STEM instruction offers
implementation approaches that focus on teaching the STEM subjects in a more connected, meaningful and relevant manners, especially in the context of real-world issues (NRC and NAE, 2014). With the advent of the NGSS, it is imperative that teachers, especially the science teachers who are expected to teach in a more integrated manner, understand some of the implementation approaches, including the challenges and the benefits to student learning. This study is centered around the belief that teachers and curriculum developers would benefit from its results by having an understanding of the nature of the implementation approaches, the assessment used, the challenges and the outcomes on student learning and teaching practice. These results may help other teachers make necessary adjustments to these approaches to suit their own different classrooms.

In my view, there is an interrelationship among STEM disciplines. For example, science learning and research relies on the usage of technological, engineering design and mathematical concepts. Engineering depends on the outcomes from science research, and the application of mathematical concepts and the usage of technological concepts and tools (California Department of Education, 2014). Teaching students in a way that assists them to make these connections could increase the relevancy of education to the student lives. Integration can serve as a way of reorganizing learning activities so that they include academic concepts and real life problems-based activities. However, this depends on how integrated STEM is implemented in schools and school settings so that it actually makes these connections explicit. The implementation has to account for the connection of the various STEM subjects involved in any task or activity. It can be difficult for students to make these connections spontaneously (NAE & NRC, 2014). This is the reason why teachers will have to make them explicit. This could be done using different instructional approaches like problem based learning to introduce STEM integration to students.
There are several pertinent questions, which need to be answered for STEM implementation to be effective, like how can teachers be better prepared and supported to teach in more integrated ways? And how can we assess student learning in integrated STEM education?

This study was also developed to add effective approaches of integrating STEM instruction in K-12 to the literature in this area. It focused on the approaches the teachers used, analyzed barriers that hindered proper implementation and examined teachers and student perspectives that are the key players in this implementation process. I will discuss the implications to teaching and learning in STEM, benefits and challenges that emerged and propose how they can be alleviated.

**Implication to the teaching of K-12 Integrated STEM**

The Next Generation Science Standards (NGSS) and Common Core State Standards for mathematics (CCSSM) have called for “deeper connections among STEM subjects” (NRC & NAE, 2014, p. 1). Furthermore, the NGSS expects science teachers to teach both science and engineering in an integrated way (NRC & NAE, 2014). However, there is not much empirical research that provides teachers with more information on how to teach in an integrated fashion or that provides some of the benefits of teaching this way. Benefits proposed include enhanced student learning, achievement, retention, and interest (NRC & NAE, 2014). This study aimed to provide answers to some of these concerns; particularly, how to implement integration, its benefits, and students and teachers’ perceptions. The outcome of this study indicated that in this case (and with this context for learning) that kind of approach did effectively support student learning. The approach was constructivist in nature, problem-based and student centered but still needed teacher’s involvement to scaffold the learning process. “Teacher involvement was central to children’s experiences in the classroom and that teacher provision of both autonomy support
and optimal structure predicted children's motivation across the school year” (Skinner & Belmont, 1993 p.571). The passion and interest that teachers had in this approach indicated that teachers found this as a useful way teaching approach and a way of knowing (epistemology approach) in STEM education. Teachers should not be discouraged from using this approach even if they lack prior experience. It is another of getting students engaged to construct and become owners of their own knowledge.

Students constructed artifacts or represented their knowledge with tangible objects as part of a learning process (Papert & Harel, 1991). In constructing the robot, the construction kit and the instructional strategy the teachers used provided the student a favorable learning environment where they could construct their own knowledge. These students constructed this knowledge by making use of several parameters like the instruction received from the teachers, their prior knowledge, in mathematics and physics, personal interest and motivation, skills learned and even sociocultural influences. Sociocultural influence could include things the student learned from their culture perhaps from watching TV or their societal influences. For example, some students mentioned that the way of learning the programming and constructing the robot was based on a robot that the student had actually seen or on some programming classes that they have received out of school. The students also were motivated by the factor that teacher was there to talk to them as they engaged in an activity in order to understand some of their perceptions and prior knowledge was important for this reason. Bruner (1996) noted, “you cannot understand mental activity unless you take into account the cultural setting and its resources, the very things that give mind its shape and scope” (pp. x–xi).

Most importantly, students mentioned that they enjoyed the fact that they took control of their learning. In my opinion, this type of project could stimulate them with the assistance of the
continuous assessment questions to reflect on what they know and what they need to know in order to learn a new idea. This is based on Piaget (1991) claim that constructivism makes us think about understanding how we know what we know and how we construct knowledge. Students can use robotics to “represent their ideas in different ways and utilize 3D artifacts (robots) to contextualize their learning and help them communicate their ideas and understandings” (Church et al., 2010, p.47). Also the results revealed that these activities gave the students the opportunities to practice and apply skills in a hands-on environment. Students acknowledged having applied problem-solving skills during the interviews, stating that the activities gave them opportunities to learn and apply concepts in the project. This aligns with Rockland et al., (2010) claim that when students integrate robotics, they acquire knowledge and improve their critical thinking skills. For instance, students learned and applied the concept of acceleration. Some of them also believed they could transfer the application to new situations. Furthermore, teachers held very positive impressions about the effect that this approach could have on their teaching practice and were all determined to continue incorporating other STEM concepts in their science teaching.

**Implications of integrated STEM instruction on student learning**

From the standpoint of learning, this example of STEM integration could be considered effective because the fundamental qualities of cognition exhibited by the students’ supports the idea that their ultimate learning featured connected concepts. This construction of connected concepts leads to meaning making. Furthermore, this connected conceptual knowledge could enhance the learner’s ability to transfer knowledge and competencies to novel situations (NAE & NRC, 2014). In this study, the eighth grade students showed their understanding of connected concepts by relating coding (a technology concept) to acceleration (a science concept). In the
sixth grade, the students related programming to the human system as they programmed their robots to navigate through the human body systems performing various tasks. In the eighth grade, in order to succeed in the tasks, the students had to understand the science concepts. For example, in order to program the robot to accelerate, they had to understand that acceleration is change in velocity per unit time and that velocity is change in distance per unit time, and that displacement is distance in a particular direction and relate that to change in the number of rotations of the wheel. At this point they could relate their coding to distance and time. They navigated through this process easily because they were very motivated, highly engaged and showed sustained interest in the projects. The students were very excited because they believed that they were given the opportunity to apply their way of thinking (the teacher never told them how to do it) and ideas in order to discover the science concepts in a more connected manner. This project was a success to the students and I believe it was due to the fact that the projects showcased the interconnectedness of STEM knowledge and were based on real life problems. This is line with the NGSS framework, which calls for the interconnectedness of knowledge and practice.

“The framework is designed to help realize a vision for education in the sciences and engineering in which students, over multiple years of school, actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields… Throughout grades K-12, students should have the opportunity to carry out scientific investigations and engineering design projects related to the disciplinary core ideas.” (NGSS Framework, p.10).
The framework further emphasizes that

“Learning about science and engineering involves integration of the knowledge of scientific explanations (i.e., content knowledge) and the practices needed to engage in scientific inquiry and engineering design. Thus the framework seeks to illustrate how knowledge and practice must be intertwined in designing learning experiences in K–12 science education.” (p. 11).

This accentuates the fact that knowledge and practice must be interwoven in developing learning experiences and it does not just limit these experiences to engineering and science but can be extended to other fields. In this research study, the students viewed learning as a constructive rather than a receptive process, and based on the analysis of data, this is due to the way the projects were developed. In developing the integrated STEM projects, the teachers made sure they were engaging, able to capture the student interest and helped students connect their ideas about science and technology concepts. This suggests that integrated STEM instruction could enhance learning provided the instruction is designed with these considerations in mind. For example, the instructional materials should enhance the interconnectedness of STEM knowledge, be engaging and able to capture and sustain student interest. This supports Sanders (2009) contention that integrative STEM activities are models of constructivist practice in education, provide a framework and context for providing students with organized understandings of science and mathematics, and help students to actively build contextualize knowledge of science and mathematics (p.23).

It is beneficial for teachers to understand, in advance of their enactment of instruction, how students feel about a particular teaching approach. Effective approaches get them excited and sustain their interest in the topic of interest. It would equally be helpful to understand how
students react and respond to a particular instructional approach or subject matter. The reaction could include how the instruction satisfies their goals. One of the important aspects of this research study was to find out student perspectives or views on integrated STEM instruction. The results showed that this approach sparked some sustained interest and motivation in students and actively engaged them in the work. I use the term, *sustained interest*, here based on the students’ own declarations and not on any specific measurement. The fact that this sustained interest enabled the students to learn about the process of engineering design, inquiry and problem solving while at the same time learning about the STEM concepts like acceleration and programing means that this instructional approach in this context was actually good at integrating various STEM contents. Even though the concepts were from science and technology, they could have come from other STEM disciplines. Here the students constructed their projects, which was a representation of their ideas, informed their science understanding and enhanced their other competencies like problem solving and critical thinking. This makes them able to monitor their own progress and reflect on their work by constantly testing and redesigning or reprogramming their robot. Thus I would assert that this is a process that needs to be inculcated into the students through the development of suitable integrated STEM curricula. An integrated STEM curriculum should be one that can scaffold the development of the process of inquiry, engineering design and other twenty-first century skills that are expected to learn. This implies that integrated STEM instruction could serve as way to promote active learning in students.
Implication of the challenges teachers encountered

When I perused the literature on integrated STEM education, I found numerous challenges that hindered its proper implementation. These barriers that the teachers encountered ranged from their lack of content knowledge to insufficient time for implementation. In this study, I learned that most of these challenges still persisted and teachers found it difficult to make necessary adjustments in both their content knowledge and practices to meet most of these challenges. Teachers faced the enormous challenge of not having the appropriate content knowledge to be able to effectively implement an integrated STEM curriculum. The teachers in this study showed a lack of technological and engineering knowledge and relied profoundly on the technology teacher for the success of the integrated STEM projects. They were, however, very proficient in the science content that was the regular subject matter of their courses. The challenge of overcoming the lack of knowledge for teaching technology and engineering could not be alleviated by a two-day workshop that the teachers attended. It just was not enough for them to succeed on their own. This implies that for an integrated STEM instruction to be successful, some assurance must be made that the teachers are adequate trained in the STEM content disciplines that will be included. There are two ways of acquiring this training: through professional development or formal college training, books, Internet, to outside school expert. For professional development, the teachers could receive training on both the content knowledge and some specific implementation examples, like the case of solar panels, which I have discussed in my integrated STEM (IntSTEM) framework, which I will present later in this chapter.

The implementation of integrated STEM education in K-12 classroom faced a lot of challenges. The ones that were identified in this study included lack of adequate instructional time. Though not all of the teachers felt this way. The eighth grade teacher felt that there was
plenty of time. This was probably due to the fact that the students were learning the exact content that he wished for them to learn (acceleration, deceleration and directional acceleration) and thus did not feel like he was doing something “special” as much as the other teachers. The time devoted to science in the middle school was used for the project. Teachers had difficulties knowing how long lessons would last and knowing how to best guide students in their work (Stohlman et al., 2012).

*Teachers need some sort of framework to guide their implementation of integrated STEM instruction*

In this study I learned that the teachers started the implementation process with no prior experience in integrated STEM instruction or the use of robotics in the science classroom. The teachers would have benefited more if they had somewhere to begin or some framework to guide them and provide some support. In the literature review, there is no framework to guide the development and implementation of integrated STEM topics. This lack of framework is another challenge. Each researcher uses a specific example, which means a teacher could only replicate that same example which might or might not fit the context or spend an enormous amount of time trying to figure out an example that fits into the curriculum. Integrated STEM framework (InSTEM) that I have proposed does not provide any content knowledge, but rather guides teachers and students to come up with their own projects that align with the standards and could help teachers with the proper implementation process. It does not answer all the implementation questions but could contribute to eventually coming up with a more comprehensive framework. Integrated STEM instruction like many integration endeavors are complex and need a lot of work and time to get it to the point where many people can accept it.
Furthermore, teachers in this study did not possess a proper conceptualization of integrated STEM education. Even though some had carried out projects that could be classified as integrated STEM projects, they could not link them to integrated STEM education. This reiterates the difficulty that comes with the conceptualization of integrated STEM education, especially in understanding it as embodying a connected body of complimentary disciplines. This connection may be achieved if teachers are exposed to explicit connections between or among STEM disciplinary knowledge and their wider practices. Weber et al. (2013) asserted “understanding of the broader practices and methods of disciplinary areas is crucial to conceiving of them as a connected body of complementary disciplines” (p.8). The stakeholders in STEM education could enhance this understanding of broader practices and concepts by clearly defining what integrated STEM education is, stating its features or characteristics and proposing some effective ways of implementing and assessing integrated STEM instruction. For example, for pre-service teachers, teacher preparation programs could incorporate integrated STEM education courses to better prepare the teachers to adopt interdisciplinary core ideas into the learning objectives. Adopting interdisciplinary core ideas into the learning objectives is a key requirement in the NGSS framework.

**The Integrated STEM (IntSTEM) Framework**

This theoretical integrated STEM (IntSTEM) framework provides some assistance on the different ways of creating activities that would be related to student learning outcomes. I have been working on it prior to this study, but this study findings helped informed it. So, I decided to include here. This framework could help inform the teaching process and support teachers who are new in integrated STEM instruction. An important aspect of integrated STEM framework is to link integrated STEM projects to the existing curriculum and student learning. This can assist
teachers when they work with students, because it can guide them on how to interpret what students do and on getting feedback from formative assessment. Getting feedback from formative assessment can help the learner to become more cognizant of the existing limitations between required goals and current knowledge (Boston, 2002; Sadler, 1989). The framework begins with preparation for instruction.

**Preparation**

In order to effectively implement an integrated STEM instruction in the science classroom, a project-based approach is one of the approaches that can be used. Therefore, the instruction could begin with an integrated STEM based project based project in a science classroom. An integrated STEM based project is one that draws knowledge from at least two STEM disciplines in a way that one concept cannot be understood by the learner without some learning with regard to the other. For example, in the acceleration task that was used in this study, students needed to understand the acceleration (change in velocity per unit time) and coding (coding and programming were used interchangeably by the teacher in this study) in order to accomplish the task. Teachers will need to begin with planning. The planning includes training (if the teacher lacks the content knowledge and integrated STEM education experience) and selecting an appropriate project that aligns with the curriculum or the standards. Training could be in the form of a workshop or any other professional development where teachers learn technological skills like programming and understanding the engineering design process. Training would also help teachers develop proper assessment techniques. In the case where it is not possible to have formal training, teachers could embark on self-study. Self-study includes selecting activities or projects from empirical studies that have used integrated STEM project and modifying them to suit your context. Other sources (for robotics activities) like the Carnegie Mellon University,
Lego (the manufacturer of the robots), and Tuft University websites could also be used. Teachers could also contact people who have more experience and knowledge to assist with the planning of the projects. For example, in this study, the eighth grade teacher invited a graduate engineering student to assist him with the design of the acceleration block for the robotics project. The teacher then acknowledged the fact that this was very helpful to the success of the project. This is the stage where the actual activity is selected.

In selecting or designing the activity for implementation, the teacher should take into consideration the curriculum or standards and make sure the activity is well suited for those standards and then figure out the type of assessment to be used. The concepts in the project should be identified and the connections among them explicitly stated by the teacher. This is because the students cannot naturally make these connections (NAE & NRC, 2014). Integrated STEM projects should be real-life based and could cover the science process skills, knowledge of the nature and practice of science, learning engineering design, problem-solving skills, and computational skills all of which are useful in real life and cannot be learned from purely science based inquiry or conventional teaching methods.

Another aspect of the planning process is writing out the lesson plan. All the teachers in this study mentioned that they spent some time planning and preparing their lesson plans. This implied that a well planned and detailed lesson plan with well-stated objectives, teacher’s activities and student activities will help the implementation. For the lesson plan, the teacher should identify the objectives from the various STEM disciplines that are involved in the project.

**Design and implementation**

In designing the implementation it is important to be explicit about the goals of the instruction and state the intended outcome for the integrated experience and how to assess the
outcome. Make STEM connections unambiguous to students and support the students to make these connections. The most common way of designing integrated STEM activities is by using projects, which are authentic and real life-based. The students interview analysis indicated that they were engaged in the project and they indicted that they were motivated by the nature of the activities. The design of this instruction has to address student learning. In this study, the instructional design included methods that were more student-centered, open-ended and involved problem-based learning. Engineering design should also be considered as a way to teach the STEM disciplines in an integrated manner. Just like science inquiry and problem-based learning, engineering design can afford students the opportunities to engage in STEM practices and apply STEM concepts. The implementation may also need extended class time so that students can have sufficient time to iterate, test and improve their design. In this study, some students needed such extended time because some of them requested to use their break time to work on their projects.

Assessment

Assessment is challenging because the method used has to measure how student learning can result from the infusion of integrated STEM units (like Robotics), into the science curricular and other STEM curricular goals. Also, integrated STEM instruction is focused on providing students with learning and reasoning outcomes that include academic knowledge and competencies like problem solving, critical thinking, collaboration, and ability to make connections among STEM concepts. To me, this makes it difficult, but not impossible to assess these outcomes. However, standardized achievement tests will be insufficient in measuring the full range of the learning and reasoning outcomes supported by integrated STEM experiences (NAE & NRC, 2014) like the ability to make connections across disciplines and their proficiency.
with competencies. There are very few assessment instruments that can be used to assess student outcomes from integrated STEM instruction. This is true because tests and theories have focused on “content area-specific concepts and procedures” and because of lack of a “widely accepted definition of integrative thinking” (NAE & NRC, 2014, p. 52). In my view, both summative and formative assessments are possible in assessing integrated STEM outcomes in students. But this requires careful monitoring of students learning because “disciplinary knowledge is structured and understanding disciplinary ideas depends on understanding how they fit with other, related ideas” (NAE & NRC, 2014, p. 52). In order for concepts to make sense as elements of integrated structures of knowledge or learning, it would require the development of those structures over prolonged lengths of time. With formative assessment the particular form that could be used is the continuous assessment, which occurs throughout the entire process, focusing on the specific STEM content and skills of interest. It targets key concepts by asking “why” and “how” questions and using strategic prompts to get students more engaged. Summative assessment could take the form of performance assessment and occur at the end of the project. In this study, the teachers used both forms of assessment in each class. They used rubrics, peer assessment, feedback from teacher, and performance assessment. In the performance assessment, students were awarded points for each task that they completed successfully.

Robotics is an example of a performance task and it is an integrated STEM based project. This means that in the building or designing robotics, students either consciously or unconsciously applied some knowledge of science, engineering, technology or mathematics. The kind of knowledge and skills applied depends on the particular robotics project being considered. According to the First Lego League (FLL) website, the FLL program is designed to show students how exciting science, technology and engineering can be. But FLL is an extracurricular
competition based activity, which is different from a curricular-based activity. It shows them that the real world engineering has to do with research and problem solving. Through the project, students learn more about the science behind the Challenge theme and better understand the work of professionals in that field. Teams will mostly encounter challenges and will have to develop innovative solutions. To do these, students will have to apply what they learned in class. The application will involve critical thinking and creative skills.

In order to find out if students actually learn the science content involved in these robotic projects, the source of knowledge that they use in these projects (where does it come from?), and finally to find ways to link classroom instruction to practice (integrated STEM projects) there are a number of steps that can be taken. It began with the selection of the project, writing the project goals, content objectives and process objectives, and linking the project to the required school curriculum to know what scientific concepts to assess. The next step was the writing the assessment items (continuous assessment and a scoring rubric), and observing the students and asking more questions (Continuous assessment). The project culminates with a formative assessment based on pre-established evaluative criteria. For instance, the assessment process for the robotics project described in this research could be as follows:

First, the particular project (like robotics) to be designed is identified by the instructor(s) or/and with some input from experts. Once the project has been identified, the goals derived from the standards of the STEM fields involved are written out and made explicit to the students. Then the teacher brings out the underlying STEM concepts, specifically the scientific concepts that are embedded in the project and which are linked to the curriculum. The teacher can use the strategy called *mapping the intended curriculum* concept developed by Ruiz-Primo, Li, Wills, Giamellaro, Lan, Mason, & Sands (2012) to determine the learning goals. According to these
authors, the purpose of mapping is (a) to deeply understand the learning goal(s) that the teacher and the students are expected to meet by the end of a science module, which in turn will help to define the constructs to be measured, and (b) to understand what the teacher and students actually have to do in order to achieve these learning goals, which will help to identify some sources of manipulation that students have to do and included in assessment item development.

In the case of the robotics, the goals will be to identify the standards (differentiating engineering and technology from science content standards) that the students are expected to meet or achieved, in order to be considered as having understood that content. The achievement is measured by their answers to the continuous assessment questions and their formative assessment (in this case their final robot performing the required task. The teacher can also make use of the recommendations from Ruiz-Primo et al. (2012) on how to implement the mapping of the intended curriculum. Based on those recommendations, I believe that in order to implement the mapping in the robotics or integrated STEM projects, the following activities have to take place: Identify the STEM knowledge and practices (in this case scientific knowledge and scientific practices) students should be able to learn if they understand the STEM module or content or and also if they understand the interconnectedness of the concepts and the design (meet all the evaluative criteria and answer the CA questions satisfactorily) (2) classify the STEM (scientific knowledge and scientific practices) by types of knowledge—declarative, or knowing what; procedural, or knowing how; and schematic knowledge, or knowing why. It is important to note that with the robotics, most of the knowledge to be used by students is at the level of procedural and schematic. The key question that each module has is, ‘What are the concepts, procedures, processes, explanations, or principles critical to the module?’ (Ruiz-Primo et al., 2012). These key questions equally apply to the Robotics project. For student to be
successful at it, they have to apply engineering design principles.

The learning objectives and the rubric can be identified and developed by the teachers. The way to easily agree on the learning goals if there are many people involved is to align them with the school or state standards. A module–map can be used to focus on activities critical to achieving the learning goals for the project, documentation required from students, materials used, graphical representations, and subject-related vocabulary integral to the lesson/activity/investigation (Ruiz-Primo et al., 2012). In order to develop an assessment, teachers could employ some aspects of the DEISA (developing and evaluating instructionally sensitive assessment) approach (Ruiz-Primo et al., 2012). This approach focuses on four steps:

- **Step 1.** Define the learning goals of the selected science modules and identify the critical concepts, principles, procedures, and explanation models to be assessed to determine if the critical learning occurred. This step also helps to identify the curriculum characteristics that can be used to manipulate the development of assessment items.

- **Step 2.** Identify the big ideas as the construct to be measured and from which the DEISA assessment items are to be developed.

- **Step 3.** Develop the DEISA items by starting with the close items—those that tap the critical concepts, principles, procedures, and explanation models of the selected science module—followed by extending the development of corresponding proximal items manipulating systematically the item characteristics.

- **Step 4.** Validate the interpretive arguments of the DEISA instructionally sensitive assessments (p. 3)
Implications for Future Research

This study, which involved five teachers and eighty students, revealed that teachers found integrated STEM instruction both as a way to help students connect STEM concepts and as a way of knowing and learning for students. This finding is contrary to the claim made by Weber et al. (2013) who in their study found that teachers viewed “it more as a teaching method than a way of knowing and learning for students” (p. 8). The two main barriers that were identified to the teachers’ effective implementation of the integrated instruction were lack of content knowledge and not knowing how to infuse an integrated STEM curriculum into their own regular science standards. The results suggest that providing more appropriate training and professional development to the teachers could alleviate these barriers. The training could be in the form of professional development for in-service teachers and integrated STEM education course to pre-service teachers. This training has to emphasize the content knowledge, practices, implementation approaches, connection between and among STEM disciplinary knowledge and skills and assessment of learning outcomes. The support has to come from not just the school administration, but from the local, state and national level.

In this study, I suggest a framework for implementing integrated STEM education in the middle school science classroom. This framework is informed by the literature on integrated STEM education, but also expanded and substantiated by the results of this research study. This integrated framework (IntSTEM) presents the main components of integrated STEM implementation and underscores the importance of showing the connections among disciplines for effective and quality implementation. Further research into the components of this implementation, especially the assessment component could help strengthen this framework and
the quality of integrated STEM instruction and helps with a better understanding of the complexity of teaching and learning in STEM education.

This study examined the instructional design and supports that were provided to the teachers during the implementation of the integrated STEM instruction. It also examined student and teachers’ perceptions of this particular instructional approach. As far as instructional design is concerned, the results revealed that the teachers mostly used the student-centered approach and open-ended activities. These activities included a problem to be solved collaboratively. Student used practices like problem solving, collaboration to solve the problems, even though the teacher neither taught them nor asked them to do so. The nature of the activities made them employ the engineering design approach. It will be helpful to research some of the effective approaches that teachers can use to implement integrated STEM instruction. This study did not measure the impact of integrated STEM education on student science achievement, even though students and teachers claimed that it helped enhance their understanding of science concepts. It would be important to examine this in subsequent studies. This will help establish a more credible case for integrated STEM education in K-12 classrooms.

Regarding the various ways teachers were provided support to enhance their STEM content knowledge and pedagogical practices, there was very little provided. The two-day workshop to train teachers on the use of a robotics kit was clearly insufficient. It would therefore be important to research some of the ways in which teachers could be supported, for example through pre-service and in-service professional development ideas.
Summary

In this chapter, I discussed the most significant results that I learned from this study. I also examined the contributions of this study to the STEM education literature, the implications of the findings for K-12 STEM teaching practice and student learning and have also presented a model for integrated STEM instruction. Finally, I provided the implications of the findings for future research and talked about the limitation of this study.

The major things that I learned from this study’s findings include: In this context the implementation of integrated STEM instruction as a project-based constructivist activity was an appropriate way to get students highly engaged, highly motivated and collaborative; that the nature and sources of integrated STEM projects are fundamental to attaining the intended outcomes of the instruction and curricular goals. Also, the study suggests being able to infuse these integrated STEM projects into the science curriculum or standards was an effective means for science teachers to expand the outcomes of the regular science course to include outcomes that are called on by the new NGSS standards.

Finally, students viewed this approach as more engaging, motivating, fun, and interesting way of learning STEM concepts and acquiring science and engineering practices. But teachers still faced the challenges of not having the adequate content knowledge in other STEM disciplines, having difficulties infusing integrated STEM curriculum or projects into their science standards. If these problems are not addressed then many teachers will be reluctant to implement this approach in their classroom.
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APPENDICES

Appendix A: Sample interview questions for teachers and students

A. Teachers

- How did you figure how to implement the technology into your classroom?
- What are the changes that you made in the process and why?
- What are the challenges or barriers that you faced during the process and how did you resolve them?
- Were there any differences in opinion among the teachers during the planning, and if so, how did you reconcile those differences?
- What impact did this technology have on your educational practice or on how you taught?
- Will you use more integrative STEM approaches in your future classroom instruction? If so how do you intend to incorporate that into your science curriculum?
- What do concepts and skills you think your students from this project?
- Did you assess this design project? Why or why not?

B. Students

- Can you explain your project to me?
- What did you like or dislike about your design?
- What did you learn from it?
- What challenges did you face?
- Do you think there was any engineering, technology, science or mathematics involved in what you did? If so, give me some examples.
Will you like to learn more of science technology engineering and mathematics in the future? Why or why not?

Have you done projects like this before? If so, explain what you did.

**Appendix B: Description of Classroom Observation Protocol**

**Arrangement of students:**

- How are students arranged in the classroom (seating arrangement)? Are they in groups, how are members engaged? Are all the members actively involved?

**Time:**

- What amount of time are students spending in each session?

**Scaffolding:**

- How are teachers helping students who have issues with their design?
- What is the methodology that teachers are using to organizing the robotics activities?
- How does the teacher keep the students active and make sure that each member participates?
- What kind of challenges are students facing? For example, they cannot understand some instructions, figure out parts of the kits, or they have problems troubleshooting their design?
- What happens to students who finish earlier?
- What about those who cannot figure things out or are unable to finish the design within time allocated?
- Prior knowledge: Is the teacher considering the students prior knowledge in design and if so what about those with no prior experience? Are they placed in special groups or given extra attention during the design process?

**Motivation:**

- Is the teacher motivating students during the process or not? If so, what is he/she saying or
doing?

**Assessment:**

- I am interested in knowing if this design project will be assessed and if so, what kind of assessment and when in the process will it be done?
- Is the assessment (formative or summative or both)? If formative, what exactly is the teacher(s) doing or expect from the students?
- If summative, when, where and how will it be done?

**Collaboration among teachers**

- Since this is a collaborative unit, teachers will seek assistance from each other. For example, a teacher might be unable to figure out why a certain part of the kit is not working right. He or she would probably have to go to another teacher like the technology teacher, to seek some help with that.

The following table will be completed during each class session observation:
### Appendix C: Observation protocol

<table>
<thead>
<tr>
<th>Date and time of class</th>
<th>Researcher’s Observation/Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arrangement of students</strong></td>
<td></td>
</tr>
<tr>
<td>Group, pair or individual?</td>
<td></td>
</tr>
<tr>
<td>Are there roles assigned to each group member?</td>
<td></td>
</tr>
</tbody>
</table>

<p>| <strong>Scaffolding</strong> | |
| Does teacher helps students only when requested or without any request? | |
| Location of the teacher during the design process | |
| Is the teacher helping the group or just one student? | |
| What are students doing when the teacher is helping other students? | |
| What kind of challenges are students facing? | |
| What are students who have finished their design doing? | |
| What does the teacher do if | |</p>
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>some students do not finish in time?</td>
<td></td>
</tr>
<tr>
<td><strong>Motivation</strong></td>
<td></td>
</tr>
<tr>
<td>What does the teacher say or do to motivate students?</td>
<td></td>
</tr>
<tr>
<td><strong>Assessment</strong></td>
<td></td>
</tr>
<tr>
<td>Is it summative, formative, both or none</td>
<td></td>
</tr>
<tr>
<td>If any, how is it done?</td>
<td></td>
</tr>
<tr>
<td><strong>Collaboration among teachers</strong></td>
<td></td>
</tr>
<tr>
<td>Are teachers seeking assistance from each other?</td>
<td></td>
</tr>
<tr>
<td>If so, when and why?</td>
<td></td>
</tr>
</tbody>
</table>