BUT, IS IT WORKING? MENTOR INVOLVEMENT IN INFORMAL ELEMENTARY STEM PROGRAMS. A COLLECTIVE CASE STUDY

by

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This degree is dedicated to the three best guys in my life. My late father Darin Anthony Rush, for being my guiding light, my wonderful husband and driving force behind this degree, Eric James Leeker, for taking over all parenting duties when I needed to research, and my sweet baby boy, Mason James Leeker, for teaching me time management and that I could survive on less sleep. Thank you all for your understanding and support in every way.

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ABSTRACT

Despite generous funding, the current data shows slow-moving demographical changes in STEM (science, technology, engineering, and math) fields, and little to no slowing in the decline of STEM-associated career interests in underserved communities (Leeker, Maxey, Cardella & Hynes, 2019). While a considerable amount has been written about the evaluation of formal pre-college STEM programs, little research has been carried out regarding the success of informal programs to encourage interest in STEM-related careers and develop skills needed to succeed in such environments.

A common method of education for elementary school students is to use informal programs, usually with the help of professional mentors. To better understand such programs, the qualitative research that formulates this dissertation is a collective case study of after-school elementary robotics programs in Indiana, the United States, which successfully implemented the State Robotics Initiative (SRI) to provide hands-on STEM learning opportunities. This program relies on mentor expertise for after-school program instruction. The purpose of this study is to investigate mentor involvement in informal STEM programs, including to answer the following research question: How do mentors impact student participants' advancement of specific engineering skills, including problem-solving, critical thinking, teamwork, and communication?

In this case study, the researcher collected documents, observed activities involving mentors and students, and interviewed mentors and students to determine how mentor involvement impacts students who participate in informal STEM programs. The researcher then conducted a holistic analysis of the data. To understand how knowledge of STEM skills gained from mentors impacts students, the researcher focused on a coding scheme to correspond with a framework developed by the Partnership for 21st Century Learning (P21).

Themes, the outcome of coding, were developed by "layering the analysis" (Creswell & Poth, 2017), first by showing unique situations of each participant, followed by grouping by the program of these unique situations into comprehensive groupings. This resulted in three separate cases covering multiple participants that serve as examples of mentor impact of specific STEM skills learned by students in three robotics programs.

While the results were not analyzed across cases, all programs sought to increase knowledge with students even though each program had a different background and reason for starting the

robotics program. In addition, each program had very different demographics and cultural styles, but all showed the integration of STEM and robotics in an afterschool program, with emphasis on problem-solving. This dissertation includes an introduction, literature review, methodology, findings, and a discussion. Recommendations for educators and future researchers are also presented in a final chapter.

1. INTRODUCTION

1.1 Introduction to the Problem

Numerous national articles have requested an increase of students in STEM to raise global competitiveness (Holmlund, Lesseig, & Slavit, 2018; Kuenzi, 2008; Tanenbaum, 2016). Along with national agencies supporting STEM, industry has formed analogous relationships to produce similar benefits that intend to provide favorable results in STEM education programs (Kuenzi, 2008). These programs extend from financial grants supporting informal and after school programs to less formal activities like employee volunteering, including involvement through mentoring.

STEM-focused education teaches students disciplinary concepts while focusing on hands-on learning and real-world applications, to develop a variety of skills, including creativity in problem-solving (Rutgers State University, 2018). While a considerable amount has been written about the evaluation of formal pre-college STEM programs, little research has been completed regarding the success of the many informal and out-of-school-time programs developed to encourage interest in STEM-related careers. Smith (2015) underscores the importance of such investigations by showing the direct link between inadequate and unappealing STEM education opportunities and the lack of students interested in STEM careers. Further, Tsui (2007) provides research outlining practical ways to increase diversity in STEM fields, presenting empirical evidence proposing ten strategies, which include mentoring and tutoring. Tsui (2007) and others also call for further research and discussion in this area.

The American Association for the Advancement of Science (1993) advised that the security and future of America are dependent upon informed individuals. These individuals are capable of reasoning and thinking creatively, making decisions, and solving problems in an everyday context. Also, according to Russell (2005), students will need preparation for careers before high school to be equipped with STEM skills to make intelligent decisions to empower their lives. The motivation of this study is to explore an area that has not yet been sufficiently explored or examined, namely the involvement of mentors to help teach elementary students STEM skills that may positively impact their lives and careers.

1.2 Statement of the Problem

The absence of early involvement of students in informal STEM programs “compounds the disparity in educational outcomes observed in formal K-12 education” (Pandya, 2012, p. 314). Informal STEM programs are intended to promote STEM awareness, shape a comprehension of critical thinking and science, and a reflection of concepts about STEM by connecting students with appealing projects (Rutgers State University, 2018). Partnerships with afterschool programs attempt to improve STEM learning by intentionally providing access to resources through appealing and progressive programs that aim to develop STEM skills (Sahin, Ayar, & Adiguzel, 2014). Mentoring is very common in these programs, but the involvement of mentors in informal elementary education has not been adequately researched. This research will investigate the impact of mentor involvement in elementary informal STEM environments.

1.3 Purpose of the Study

The purpose of this study was to examine the involvement of mentors that help teach elementary students STEM skills in the context of after-school programs. By investigating the roles and relationships of mentors and elementary students in informal STEM programs, contributors to STEM education can be empowered to generate corrective action to enhance student engagement with STEM domain areas and skills and remain on their mission to cultivate students who are passionate, engaged, and knowledgeable. However, this research does not attempt to define success in all mentor programs or to categorize mentoring styles. Instead, the study focuses on themes that specifically address how mentoring impacts students, including critical STEM skills that can be developed through such informal STEM programs.

1.4 Research Question

This research explores the participation of mentors involved in informal elementary STEM programs. The fundamental research question within the study is:

> How do mentors impact student participants’ advancement of specific engineering skills, including problem-solving, critical thinking, teamwork, and communication?

1.5 Study Design Overview

This collective case study focused on the active involvement of mentors and student participation in informal STEM programs at three after-school elementary robotics programs in Indiana. Case study analysis involved understanding how individuals experience a situation as it occurs (Stake, 2013). For this research, this required multiple visits to each robotics program for observations, interviews, and document collection.

The researcher collected extensive information to conduct a holistic analysis of the data. To understand how knowledge of STEM skills gained from mentors impacts students, the researcher focused on developing and using a coding scheme to correspond with the Partnership for 21st Century Skills (2011) STEM framework.

Themes were created by "layering the analysis" (Creswell & Poth, 2017), first by showing unique situations of each participant, followed by grouping by the program of these unique situations into comprehensive groupings.

1.6 Assumptions and Delimitations

1.6.1 Assumptions

Assumptions are substantial components of a study that are beyond the control of the researcher (Weick, 1984). This study assumes that all participating students received STEM instruction as part of their typical classroom experiences based on the Indiana Afterschool STEM Standards (2018). This study also assumed that the respondents provided honest, candid, accurate, and valid responses during interviews.

The researcher believes that the qualitative research design serves as a suitable technique of research for this study because it led to rich, detailed understandings of the phenomenon of the study. The study used a collective case study design to gather multiple perceptions when the researcher had little control over events (Yin, 2017); the depth of detail collected for each case limited the total number of cases collected. The small sample size limited this study; therefore, the results may not be generalizable to all after-school elementary robotics programs with mentors. The size of this study could have been expanded to include more after-school elementary robotic programs with mentor involvement in robotics programs in Indiana.

Communicating and gaining support from programs may have also improved contribution. A guardian's consent for involvement was mandatory because of the involvement of children. Guardians had the option to exclude their child's involvement in the study, thus possibly depressing the response rate. Additionally, students who engage in robotics may be inclined to enjoy STEM subjects. Acknowledging that students may be predisposed to learning is a form of recognition concerning self-selection bias. Lastly, due to the length of the study, there was potential for the availability of respondents to decrease from the beginning to the end of the study. These respondents could have been inaccessible or reluctant to participate until the end.

1.6.2 Delimitations

The delimitations within this study are concerned with the intent of the research and provide an understanding of what the study will not address. The intent of this study is to identify effective behaviors and skills needed by both mentors and students to strengthen student's skill development and other outcomes. The participants were students and mentors who were actively involved in their respective after-school robotics program. This study did not examine elementary robotics programs without external mentors.

Additionally, even though mentor data was collected for this study, it was out of scope for the final research question. Lastly, the sample size is comparatively small, covering just three robotics programs in one state, Indiana. Because of this, the study might not provide sufficient data to identify certain subtleties in the mentoring dynamics, thus limiting the ability to generalize or transfer findings to a larger population or other settings.

1.7 The Significance of the Study

As this research is shared, care will be taken to publish findings in both academic publications and in formats that reach STEM outreach programs and industry. There is an overall lack of detailed knowledge if mentors are participating in a variety of informal roles, including mentoring, and limited knowledge is available if this is indeed working (Karcher, Kuperminc, Portwood, Sipe, & Taylor, 2006). According to the National Mentoring Resource Center, the Sea Research Foundation, Inc. (SRF), which is a STEM mentoring program provider, works with approximately 3,000 youth among 100 sites spread among 35 states and in Puerto Rico (Batt, 2016). SRF is just one example to show the impact of mentoring. Even though the number of mentoring programs is substantial, literature is lacking in the studies of mentor involvement in pre-college education (DuBois & Rhodes, 2006).

By examining mentor involvement using a qualitative approach, this study aimed to develop a better understanding of mentor participation and impacts. Direct benefits of this work included an opportunity to connect the domains of education and mentoring, and by sharing a systematic collection of researched insights with critical “external” audiences and stakeholder groups. Provided with this information, directors of informal outreach programs can strategically and accurately refine operational approaches to meet the need for STEM education while advancing impactful STEM programs that might efficiently and effectively increase diversity in the workplace (Moskal et al., 2007). In addition, researchers can better isolate variables and develop new models for studying how mentor participation directly affects students. Lastly, parents can better understand STEM practices and assist their children in the development of STEM skills.

1.8 Definition of Terms

Even though many scholars in engineering education acknowledge the following definitions, variations occur as engineering education is expanding.

Afterschool Program: A program, sometimes also called out-of-school time, that serves children of all ages and can include mentoring, development, and/or academic support (Roth & Brooks-Gunn, 2003). Afterschool programs are one dimension of out-of-school time.

Communication Skill: A P21 Learning and Innovation Skill that students demonstrate through expression using various exchanges of information by way of various tools, transmissions, and methods (NCREL & Metiri Group, 2003).

Critical Thinking Skill: A P21 Learning and Innovation Skill that involves “purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation…upon which judgement is based” (Facione, 1990, p. 3).

Elementary: A school for students in their first school years, typically for kindergarten through fifth or sixth-grade students.

Informal Learning Environment: Refers to settings where learning transpires outside of a structured, formal environment (Hung, Lee, & Lim, 2012). Informal learning environments are essential not just because they allow learners to gain knowledge, but also because the learner is developing an interest in a topic, gaining skills, and building confidence that may impact their identity through a more hands-on approach.

Information Literacy: This is a part of critical thinking that provides the actual tools for evaluating the information given as well as requiring students to identify when information is required and how to use the required information effectively (Paul & Elder, 2006).

Mentor: An adult volunteer who provides students with the opportunity to learn from experienced professionals and to further their awareness of potential career opportunities.

Mentoring: A connection between two individuals (mentor and student) that promotes student growth by offering guidance, inspiration, and structure while permitting the student to be the agent of their growth (Dubois & Rhodes, 2006).

Out-of-School Time: includes afterschool programs, science museums, zoos, and planetariums that serve children of all ages and may provide mentoring, development, and academic support (Bevan et al., 2010).

Pre-College Education: Education before college, including pre-school through twelfth grades.

Problem-Solving: Although there are many styles and types of problem-solving techniques, for this study, the style of problem-solving reflects the teachings that are commonly seen in STEM education. More specifically, problem-solving is the ability and skill to unravel different situations that are unfamiliar and to make decisions about the best sequence of action through creativity, collaboration, or resourcefulness (P21, 2009).

STEM Literacy: STEM literacy is the ability of students to use learned concepts of science, technology, engineering, and math to understand and solve complex problems (Tseng, Chang, Lou, & Chen, 2013).

STEM: Acronym that stands for Science, Technology, Engineering, and Mathematics

STEM Mentor: An adult volunteer who provides students with the chance to learn from knowledgeable professionals working in STEM fields and to further their awareness of potential career opportunities.

STEM Skills: An amalgamation of understanding and skills that are considered necessary for success in STEM. These skills include critical and systems thinking, teamwork, non-routine problem-solving, and effective communication (Windschitl, 2009). STEM skills are used to enable students to gain STEM literacy to use STEM concepts effectively.

Teamwork Skill: A skill that includes the expertise that involves "interaction between two or more individuals working together to solve problems" effectively (NCREL & Metiri Group, 2003, p. 47).

TechPoint: TechPoint Foundation for Youth is a not-for-profit organization in Indiana focused on inspiring students in STEM.

Troubleshooting: An aspect of problem-solving, "troubleshooting is a practice that allows engineers to reach an optimum solution by identifying problems, developing suitable solutions and improving them" (Ehsan, Leeker, Cardella, & Svarowsky, 2018, p. 4).

1.9 Summary and Overview

The purpose of this study was to examine the involvement of mentors to help teach elementary students STEM skills that may impact their lives, and through the findings, explore the future of mentor involvement in informal STEM programs. As employed in this study, the four STEM workplace skills of problem-solving, critical thinking, teamwork, and communication were based on verified research from the Partnership for 21st Century Skills (P21, 2009). TechPoint Robotics teams in Indiana served as the population of the study.

The remaining portion of this dissertation contains four chapters. Next is Chapter 2, the Literature Review, which provides a comprehensive review and examines the STEM skills and frameworks used in practice that will guide the study and frame the analysis. Chapter 2 also examines learning theories and programs related to informal STEM education and discusses the involvement of mentors in K-12 education. Chapter 3 Methodology describes the study methods and discusses the process of data collection and analysis. The research problem is reiterated as well as explaining the intent and research design. Chapter 3 presents the background of the study as well as procedures that were taken in addition to classifying the target population. By explaining the population, Chapter 3 identifies and presents the procedures followed for the actual study. The collection of data, analysis of data, discussion of anticipated findings completes Chapter 3. Chapter 4, Findings, presents the results of the content analysis as framed by the theory. Finally, Chapter 5, Discussion and Conclusions, offers further discussion of the findings, along with recommendations and plans for future work.

2. LITERATURE REVIEW

2.1 Introduction

This review discusses and analyzes the literature regarding STEM skills, informal STEM programs, pre-college robotics, and mentoring with elementary school students, including significant factors identified as important for increasing preparedness and motivations for students and mentors. First, this review promulgates the importance of STEM skills, informal education, robotics, and mentoring. Next, this review identifies the theoretical framework associated with this study. Lastly, this chapter examines the importance of the development of STEM education in early education.

In reviewing the literature on effective mentor and student relationships, most of the research studies dealt with high school relationships and beyond, the success of these partnerships, and factors related to successful partnerships. In addition, the competencies or skills needed by mentors and gained by students to implement a successful partnership have not been addressed in the literature. Identifying the STEM skills necessary for students may provide useful information to guide mentor-student relationships in the future. This literature review separately covers STEM skills, informal STEM programs, pre-college robotics, and mentoring in elementary students. At the end of the chapter, the importance of these topics, and the need to study them together is shown.

2.2 Literature Review

2.2.1 STEM Skills

Gaps between STEM education and workplace skills have been identified in industry and academia alike (Jang, 2016). However, little is typically taught to elementary school students to lay the groundwork for STEM skills (Kazakoff & Bers, 2012). Kazakoff and Bers (2012) studied 54 children to show that the use of technology in a robotics context directly affected students learning STEM skills. In another study, Rogers and Portsmore (2004) extensively studied STEM integration for elementary students. In their work, they found that the process of including STEM concepts in the classroom led students to have more hands-on experiences and promoted creativity. In addition, students were able to develop skills to apply, connect, and repeat this knowledge in various settings based on what is going on in the student's life (Brophy, Klein, Portsmore, &

Rogers, 2008; Rogers & Portsmore, 2004) indicating that the earlier these skills are presented to students the better (Metz, 2008).

STEM education, which usually emphasizes science and mathematics, also includes technology and engineering to help students "develop different strategies in order to solve interdisciplinary problems and gain skills and knowledge in order to solve interdisciplinary problems and gain skills and knowledge in order to sustain scientific leadership and economic growth" (Sahin et al., 2014, p. 309). In addition, there has been an increased interest in research on how STEM can contribute to stimulation in early brain development and researching STEM skills for early learners (Blair, 2002). Concentrating on engineering in STEM in the early years of childhood development is one potential place to start engineering education (Bagiati & Evangelou, 2009). Research findings suggest that the STEM skills that students acquire at a young age lay the groundwork for a successful trajectory in STEM (Woolley, Strutchens, Gilbert, & Martin, 2010). These STEM skills include the capacity of students to be able to inquire about an experience, work independently, and to problem-solve in such situations (Wilkins, Devey, & Bristol, 2016).

STEM skills not only help students with learning new strategies, but STEM programs have also been found to have an impact on skill development. To understand the importance and effectiveness of STEM education and 21st-century skills in robotics, Eguchi (2014) surveyed 796 U.S. participants in robotic world championships about their learning experience of STEM skills. Some of the top skills gains based on survey data included problem-solving, critical thinking, collaboration (teamwork), and communication skills.

Another study by Ma and Williams (2013) examined the experience of a robotics team to explore the teaching of 21st-century skills and the engineering design process. This qualitative inquiry of six children on a robotics team included data sources, including coaches' field notes and interviews with the students. The researchers found that for children to remember and use 21st-century skills and the engineering design process, articulation and reflection are critical.

Although STEM experiences can help students develop a variety of skills, many studies have focused on a variety of skill areas often viewed as the main focus in STEM education. Namely, problem-solving, critical thinking, teamwork, and all methods of communication (verbal and written) are commonly described as lacking in recent STEM graduates (Radermacher & Walia, 2013; Tang, Lee, & Koh, 2001). Partnership for 21st Century Skills (P21) promotes these workplace skills for all students. P21 developed a system of fundamental skills highlighting the

"3Rs and 4Cs" (P21, 2009). Reading, writing, and arithmetic (3Rs) serve as the foundation for student learning. The P21 emphasizes that the 3Rs and 4Cs (creativity, critical thinking, collaboration, and communication) are critical for today's workplace. Because the 4Cs contain the skills of creativity in problem-solving, critical thinking, collaboration in teamwork, and communication, they are the focus STEM skills in this study.

Problem-Solving

As Jang (2016) proposes, "problem-solving that addresses ill-defined problems and demands the evaluation of multiple solution paths should be more encouraged in STEM education programs" (p. 297). One specific aspect of problem-solving in STEM is called troubleshooting. Troubleshooting involves processing information, ideas, and options that can be applied to diagnose a specific situation, which can then solve a situation (Ehsan et al., 2018).

Critical Thinking

Critical thinking encompasses inference and conversation, which has a vital role in galvanizing problem-solving (Chaffee, 1994). Critical thinking also involves awareness of thinking and reflection among self and others (Kuhn & Dean, 2004). Critical thinking involves a set of skills that students can utilize to find a solution when faced with problems, ideas to evaluate, or decisions to make (Ernst & Monroe, 2004). In a systematic review of 45 studies on educational robotics, Anwar, Bascou, Menekse, and Kardgar (2019) supported the notion that robotic integration critical thinking and other engineering competencies. One specific aspect of critical thinking in STEM is information literacy. In the context of critical thinking, information literacy can be viewed as the ability to be intentionally mindful of information to understand options available to assist with critical thinking and to assess the effectiveness of the strategies formed from the options (Paul & Elder, 2006).

Teamwork

Teamwork skills are an exchange between people working together to problem-solve or carry out certain tasks (NCREL & Metiri Group, 2003). Teamwork can be effective when members share a mutual goal, and each member's role is clear (Jang, 2016). Menekse, Schunn, Higashi, and

Baehr (2015) also suggest that "working effectively in teams is one of the most critical 21st century skills" in a robotics competition while measuring team performance (p. 1). Teamwork is an essential skill; teaching this skill is imperative in pre-college education, especially since employers have expressed concerns about a lack of collaboration among recent engineering graduates (Jang, 2016).

Communication

Communication skills are expressions using various exchanges of information by using various tools, transmissions, and methods (NCREL & Metiri Group, 2003). As Jang (2016) states, "STEM education programs can promote communication skills as students practice technical writing and speaking in learning contexts" (p. 94). Researchers also propose that attention to verbal and written communication earlier in education can be advantageous throughout an engineering student's career (Jonassen, Strobel, & Lee, 2006).

One way to increase the talent pool for STEM careers and develop STEM skills is to improve STEM programs in K-12 education (Committee on Prospering in the Global Economy of the 21st Century, 2007). "In support of this argument, connections are drawn between approaches correctly used in industry and the skill-set needed to participate in informal STEM programs for pre-college students" (Leeker, Maxey, Cardella & Hynes, 2019, p.15). Additional research shows the importance of applying STEM skills to explicit actions (Jacobs, 2010; Wagner, 2008). These skills involve the use of information attained to gain more knowledge or to solve problems (Wagner, 2008). For example, researchers have argued that these skills consist of problem-solving, critical and systems thinking, effective communication, and teamwork, and leadership (Association for Career and Technical Education, National Association of State Directors of Career Technical Education Consortium and Partnership for 21st Century Skills, 2010; Windschitl, 2009).

Educating students about the world around them, and their experiences are essential in any educational setting (Bers, 2008). Additionally, The National Government Association (2007) defined STEM literacy as it "refers to an individual ability to apply his or her understanding of how the world works within and across four interrelated domains" (p. 7) of problem-solving, critical thinking, teamwork, and communication. STEM development and literacy are based on children's proclivity to create and dismantle items to grasp how they function (Carr, Bennett, & Strobel, 2012; Resnick, 2007).

2.2.2 Informal STEM Programs

Informal STEM programs, including afterschool programs, have a strong possibility to encourage young student education and advance scientific literacy, engineering thinking, and math and technology aptitude (Raizen, 1995; Robelen, 2011). Within the past decade, there has been a rise in such informal programs (Repenning, Webb, & Ioannidou, 2010). As informal STEM programming can take a variety of forms, the opportunities are too numerous to track. Access to informal STEM programming could include classroom field trips, museum visits, television programming, special STEM events (e.g., library and community events), and camps. Research indicates that informal STEM programs, in conjunction with formal STEM programs, significantly increase the amount of time available to explore STEM topics (Dorph et al., 2007). That is, as students devote a substantial amount of time outside of school, there is an opportunity to leverage this time to offer programming to support STEM learning (see Figure 1). Informal STEM programs can assist in closing the education gap between what students learn in school and what is needed to succeed in the workplace by offering engaging education to a diverse group of students (Duncan & Murnane, 2011).

Individual curiosity and awareness are also critical components in inspiring students to explore STEM (Mohr-Schroeder et al., 2014).Additionally, interest and positive attitudes towards STEM can help students develop a curiosity in these subjects outside the classroom (Buxton, 2001; Capobianco, Diefes-dux, Mena, & Weller, 2011). Some informal pre-college programs allow students to perceive the rigors of a university environment as well as other hands-on involvements to help all students have an equal opportunity for higher education (Fenske, Geranios, Keller, & Moore, 1997). Informal pre-college programs aim to supply students with the tools needed to attain higher education (Gándara, Larson, Mehan, & Rumberger, 1998).

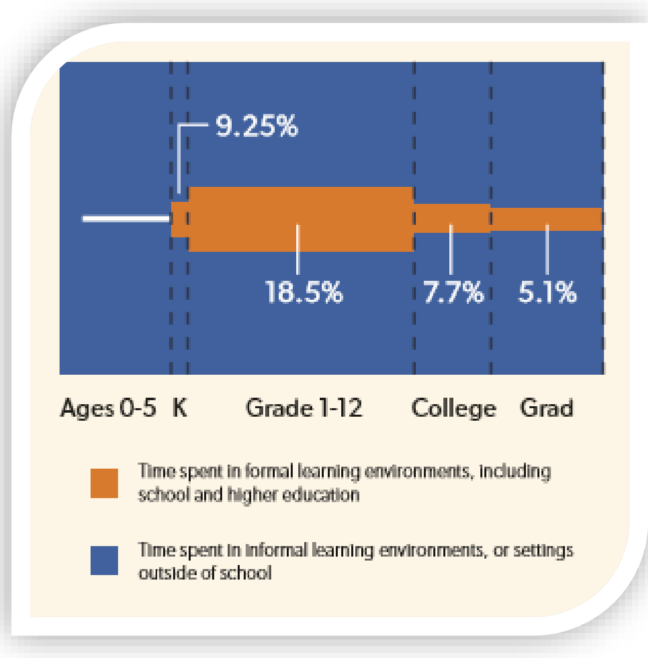

Figure 1. By utilizing the time available to students after the school day, informal STEM programs can help close the education gap. (Source: The Life Center's Lifelong and Lifewide Diagram)

Although formal STEM exposure has been proven effective in encouraging student pursuits om the sciences, the National Research Council (2011) believes that informal STEM "integration should be included in pre-college learning to help strengthen knowledge and awareness in STEM fields" (Leeker, Maxey, Cardella & Hynes, 2019, p.2). This exposure to informal STEM programs will have long-term effects of increasing interest and motivation in STEM (Wai, Lubinski, Benbow, & Steiger, 2010). Informal STEM programs permit students to experience and "become more deeply involved in STEM activities and concepts that might not be possible in more formal educational settings" (Nugent, Barker, Grandgenett, & Adamchuk, 2010, p. 404).

Changes in instructional priorities and the absence of resources for students have driven the National Science Foundation (NSF)'s 21st Century Learning Community Learning Centers to expand learning-of-STEM resources surrounding the informal learning space (National Institute on Out of School Time [NIOST], 2011). The modification has strengthened the urgency nationwide to improve STEM skills. Even though science centers and museums have provided valuable informal programming, after-school programs have implemented data-driven programs to grow participation in STEM activities that support in-school learning (NIOST, 2011).

Early involvement is increasingly understood as raising awareness for students to attend college (Fouad, 1995). The Afterschool Alliance (2011) evaluation found that when pre-college students attended high-quality STEM afterschool programs, students increased their STEM knowledge and skills. In addition, these students reported having a sense of awareness, which enabled them to grasp the concepts of various STEM careers (CSTEM, 2018). Rittmayer and Beier (2009) believed that vicarious experiences within STEM programming assist young students in their development of self-efficacy. Students who were engaged in these activities “set more challenging goals and work harder to accomplish those goals than students” (Rittmayer & Beier, 2009, p. 5). In these programs, students can learn STEM skills, including communication and scientific reasoning (Czerniak & Lumpe, 1996; Fisanick, 2010).

In summary, research has suggested that students who participate in high-quality STEM informal programs have improved attitudes towards STEM fields and careers, enhanced learning of STEM skills, and an increased interest in STEM careers.

2.2.3 Pre-College Robotics

One specific form of pre-college STEM education that has become popular nationwide is robotics programs. Robotics is prevalent in industry and applied in an assortment of areas, including medical, education, automotive, and risk mitigation (Eguchi, 2014). These fields require a specific skill set that students in STEM programs can learn, as described by Sahin (2013):

> Robotics activities included designing, programming, and problem-solving activities through ready-made computer software. For example, students worked in collaboration to build, design, and test their model. They presented their design to audiences during competitions. (p. 7)

Broadening participation in STEM through robotics creates a necessary pathway to the field of science and technology (Leonard et al., 2016). Sarama et al. (2018) indicated that quality STEM learning requires structure and time. Mentoring can be used to broaden participation and is also encouraged in pre-competition, during the competition, and post-competition as assistance is needed in all stages of robotics design and programming (Chung, Cartwright, & Cole, 2014). According to Martin (2000), robotics competitions involve students in fixed and flexible situations.

Robotics programs have the potential to improve STEM learning and STEM achievement with support from mentors and other similar leaders (Chung et al., 2014). Early educations and mentors of STEM programs can encourage young students' sense of discovery and reasoning abilities (Sarama et al., 2018).

No age is too young to introduce robotics to students (Mataric, Koenig, & Feil-Seifer, 2007). "Robotics facilitates cognitive as well as motor and social skills development, which are all important for young children" (Bers, Seddighin, & Sullivan, 2013, p. 358). In a study led by Petre and Price (2004), the researchers directed interviews, took notes, and made observations at robotics competitions following 17 teams. The findings indicated that through robotics and problem-based learning, students could learn the underlying principles of teamwork and information sharing. In an additional investigation of K-8 robotics teams, Menekse et al. (2015), found that robotics not only provided opportunities to work towards a shared goal while working in a team for students, but also showed the importance of quality collaboration as critical to team performance.

In the past several years, interest in robotics has increased (Benitti, 2012), and there is clear evidence that robotics programs can be used as engaging educational tools (Miller & Stein, 2000). Thus, robotics programs make it possible for students to work through problems and experiment with concepts that are learned by providing a technology platform to create, program, and design robots. As Eguchi (2014) stated, "educational robotics is an all-in-one technological learning tool that promotes the future success of our students and should be integrated more and more into school curriculum" (p. 33). In such settings, students are more inspired and able to increase curiosity for robotics since active learning can be more interesting (Sahin et al., 2014). After studying how to successfully implement robotics programs for elementary and middle school using a mixed-methods study of 300 students, Karp and Maloney (2013) determined that pre-college robotics is also multidisciplinary and demonstrates STEM concepts in an interrelated method by active experimental learning. Additionally, researchers argued that participation in robotics could improve cognitive and intellectual development (Karim, Lemaignan, & Mondada, 2015). In a quantitative pilot study involving 32 elementary school students, Barker and Ansorge (2007) showed that informal STEM programs had successfully used autonomous robotics programs and robotics competitions to increase interest in STEM. Pre-college robotics programs can also be used to include girls and other groups that may not have had an interest in robotics or positive attitudes toward science and engineering (Weinberg, Pettibone, Thomas, Stephen, & Stein, 2007).

2.2.4 Mentoring

Primarily, the importance of career advertisement and industry outreach in educational settings in the United States is drawn from the progressive era (Allen, 2003). However, the success of informal pre-college STEM programs has not been studied expansively. “This slow movement does not mean that the activities have served no benefit but provides an opportunity to investigate what approaches are working or not working so well” (Leeker, Maxey, Cardella & Hynes, 2019, p.1). One more specific method of support that has proven successful in the enhancement of educational programming is having mentors, often from industry. The history of mentoring, as outlined by Kram (1985):

> Derived from Greek mythology, the name implies a relationship between a young adult and an older, more experienced adult that helps the younger individual learn to navigate in the adult world and the world of work. A mentor supports, guides, and counsels the young adult as he or she accomplishes this important task. (p. 2)

Mentoring “emphasizes developing the ‘whole person’ over relatively long-term horizons” (Sosik, Lee, & Bouquillon, 2005, p. 106). Studies suggest that mentors can provide opportunities for students to form a supportive relationship, achieve better grades, establish goals and aspirations, and improve self-esteem (Green, 1993; Morgan, 1993). Because of the emphasis on the ‘whole person,’ studies advises that valuable relationships with a mentor have constructive outcomes on students. These outcomes promote individual development, educational growth, and professional creation of relationships (Schweinle, Meyer, & Turner, 2006).

More specifically, Wallace (2014) studied four robotics teams to investigate the success of mentors in the expansion of workplace skills in high school students. Using Vygotsky’s zone of proximal development, this research stressed learning as a collective action requiring the contribution from an adult like a mentor. The findings indicated that mentoring has an encouraging effect on the development of STEM skills for high school students, especially teamwork, problem-solving, critical thinking, and teamwork/collaboration.

At all levels of education, STEM career holders earn 11% higher wages compared to their counterparts (Thomasian, 2011). However, students are not choosing to pursue STEM careers because of a lack of information about how the career aligns with the individual’s interest (Hirsch, Carpinelli, Kimmel, Rockland, & Bloom, 2007). Mentoring is one possible path to offer specific examples to students and can be presented at any phase, including elementary (Terry, 1999). Ellis Paul Torrance, a psychologist, studied the importance of creative mentoring experiences for students. He explained that specific examples demonstrate STEM career options, as research has shown that those who have had mentors in the past usually go on to complete more years of education than those without such a mentor (Torrance, 1984). STEM mentors in elementary school programs can thus support STEM learning for students at an early age.

Further, the National Science Board (2007) found that elementary school educators may not have adequate knowledge to implement STEM or STEM skills to prepare students. The need for students to be effective in careers start with skills that should be developed in elementary school (Jacobs, 2002). Mentors can model positive and applicable skills essential for career growth, including communication and problem-solving (Rhodes & Lowe, 2008). Mentoring is influential in emphasizing the growth of a skill and is suitable for teaching workplace skills (Karcher et al., 2006).

Tsui (2007) identified effective options to grow participation in STEM fields by offering possibilities for further involvement in encouraging additional exploration and dialogue. This study identified mentoring programs as a practical approach that has become largely executed in various ways. Specialized mentors have a lot to contribute to the education of students, and the opportunity to form natural relationships with students are probable to be effective (O'Neill & Harris, 2004). Researchers show that the interaction with specialized mentors, such as from STEM fields, is a substantial influence when deciding a career for students (Demetry et al., 2009). Mentors can also use skills developed in a work setting to teach students through career experiences.

Even though a considerable amount has been written about the evaluation of formal (i.e., school-based) STEM programs, little research has been completed regarding the success of many pre-college informal programs in STEM disciplines. Further, opportunities for mentors to bring their knowledge in the context of informal STEM activities should not only increase industry skill development for pre-college students (Caligiuri, Mencin, & Jiang, 2013) but also make STEM applicable and alluring (Seiler, 2001).

One-on-one mentoring is often explored in the literature. However, group mentoring, especially in student programs, may also play an important role. Group mentoring is a relationship to secure wisdom and experience from multiple people (Huizing, 2012) and can help extend resources in a program which may be strapped for time and mentorship support (Herrera, Vang, & Gale, 2002). In the past, group mentoring was usually created based on a topic that was discussion-based and was a safe and supportive arena (Single & Single, 2005). Now, group mentoring includes problem-based topics, as well. Philip and Hendry (2000) acknowledged group mentoring as one of the five types of informal mentoring. Sipe and Roder (1999) estimated that more than 20% of mentoring for students is group mentoring.

Group mentoring is the "population consisted of a polyad mentoring relationship of more than two people in which the interactions were simultaneous and collaborative" (Huizing, 2012, p.28). Group mentoring usually includes anywhere between two and dozens of students with one or more mentors (Herrera, Grossman, Kauh, & McMaken, 2011). In another paper, Hirsch and Wong (2005) described group mentoring that is frequently in a natural setting, as in Boys and Girls Clubs. Even as the involvement of group mentoring has enhanced, comprehensive research on the topic has yet to occur (Huizing, 2012). Several students involved in continuing relationships with one or more mentors is one of the most common formats for student mentoring (Kuperminc & Thomason, 2013). However, some may argue that group mentoring may not have the same effectiveness as one-on-one mentoring, as there is not the same intensity of focus (Rhodes, 2005).

Students are often placed in groups for many reasons, both in education and recreation settings, that are natural environments for group mentoring (Hamilton et al., 2006). In such settings, research indicates that mentors were able to build trust and respect with children in a group environment (Hirsch, Deutsch, & DuBois, 2011). However, to be fully effective, group mentoring must include deliberate motivation (Kuperminc & Thomason, 2013). DuBois and Karcher (2005) identified three core elements needed for effective group mentoring relationships, including mentors with experience, offering guidance to assisting in the development of mentees, and the creation of a bond between mentors and mentees.

Because the enrollment gap persists in STEM programs, there is a significant need for STEM professionals and accompanying mentor involvement in supporting STEM education programs to be successful (Davis & Veenstra, 2014). The role of the mentor in this setting is facilitated by "(a) intentional learning, (b) examples of failure and success, (c), storytelling, (d) developing maturity, and (e) a sense of joint venture" (Kaye & Jacobson, 1996, p. 44). In addition, mentoring in this form can reinforce technical knowledge, time management, and team involvement skills by having more than one mentor at one time (Kavanagh & Crosthwaite, 2007). Sahin et al. (2014) performed case study research – including observation, interviews, and notes – to explore the characteristics of after-school programs involving mentors to progress 21st century STEM skills. This study focused on charter schools that served a kindergarten through the 12th-grade student population. The impacts of mentor relationships can also be a connection between students to achieve their long-term goals (Sahin et al., 2014).

2.3 Theoretical Framework

The research question and theoretical framework guides this research in its entirety. The theoretical framework for this study, as shown in Figure 2, was developed to evaluate the impact of mentor involvement in informal STEM elementary programs. Educational researchers like Vygotsky (1978) emphasized that learning is a social activity and stimulates cognitive development.

It is significant to note that while topics of mentoring have been discussed, little has been reviewed regarding their emphasis on mentor-involved programs for youth in engineering. To impart applied skills, it is important to comprehend how students absorb knowledge and develop STEM skills, which are clustered.

With informal STEM programs, students are involved in hands-on activities with industry, and this can potentially raise the number of students in STEM careers (Tsui, 2007). The development learned in hands-on experiences is vital for a student to grow to possesses the critical skills of problem-solving, critical thinking, teamwork, and communication.

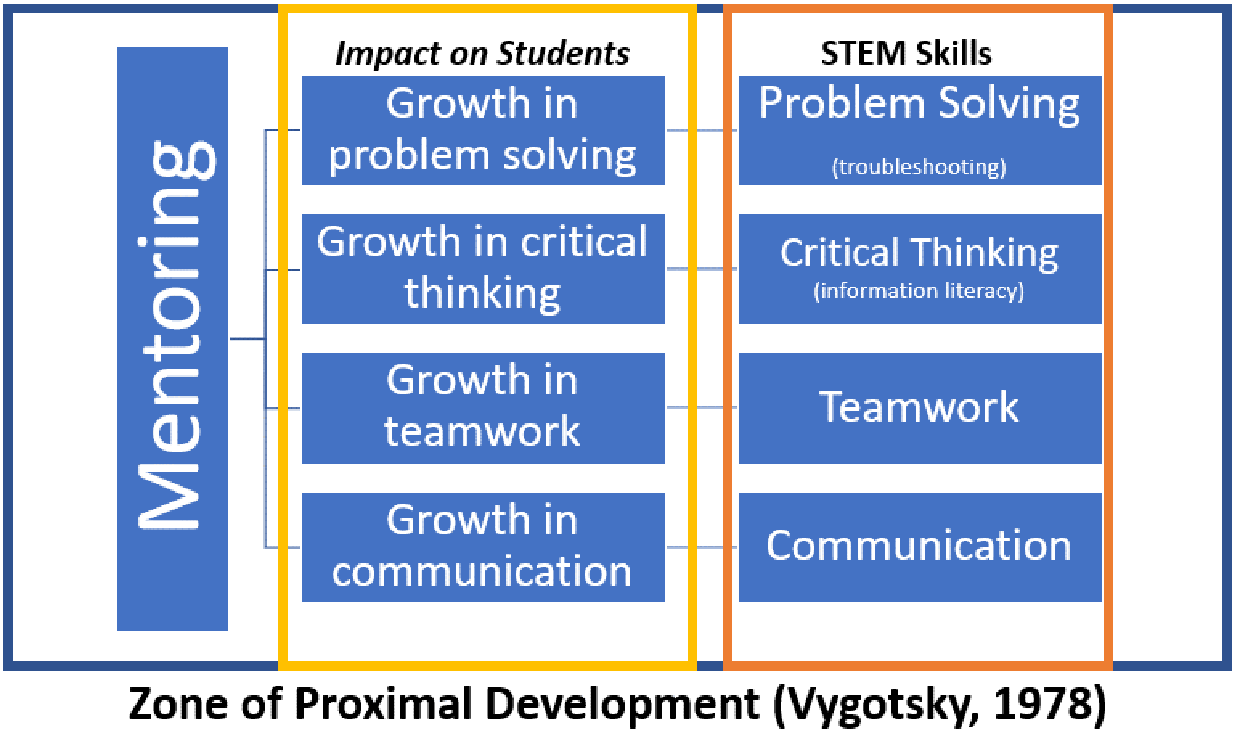

Figure 2. The theoretical framework for this study of how mentor involvement impacts students as a method for the growth of four STEM skills. The STEM skills are assembled from the Partnership for 21st Century Skills (P21).

Vygotsky recognized that early childhood is the most important time to influence children's trajectory of learning (Kauerz, 2018). Vygotsky worked on childhood development, and learning with adult guidance is the hallmark of the zone of proximal development. The foundation of Vygotsky's (1986) theory is the zone of proximal development or the "place at which a child's empirically rich but disorganized spontaneous concepts 'meet' the systematicity and logic of adult reasoning" (p. 1). In addition, "the zone of proximal development defines those functions that have not yet matured but are in the process of maturation functions that will mature tomorrow but are currently in an embryonic state" (Vygotsky, 1978, p. 86). Vygotsky describes the zone of proximal development as the place between the most onerous task a child can do by themselves (actual) and the most onerous task a child can do with help from someone else (potential). This process can be seen as a kind of scaffolding (Brophy et al., 2008), and collaboration is vital for this transmission of information. According to Vygotsky's interpretation, a child can appreciate advanced perceptions by being in experiences where ability levels are pushed. The zone of proximal development highlights developmental abilities and knowledge through collaboration (Mooney, 2013). Children can achieve more through scaffolding than what she or he can do alone (Vygotsky, 1978).

Problem-solving, critical thinking, teamwork, and communication can be educated through scaffolding. If a student is close to gaining an understanding of a problem, a mentor can help that student gain the knowledge needed to more fully understand (Delaney, O'Keeffe, & Fragou, 2017). A mentor conveys practical knowledge and can assist in bringing theoretical understanding to life. Mentors can also share interdisciplinary knowledge for problem-solving. Vygotsky's zone of proximal development is an essential aspect of mentoring, as mentors can offer available areas to inspire a student (Larson, 2006). Through a collective effort with the student, mentors can cultivate students' concepts and assist them to encompass their knowledge further (Rhodes & Lowe, 2008).

Research by Yuen, Ek, and Scheutze (2013) helps illustrate how mentors can positively influence students in a robotics program. To motivate students in an underserved area, these researchers conducted a study using an after-school robotics program to target students in the community. By assigning mentors to students in the program, the program was effective and successful in establishing ongoing relationships as well as future mentorships opportunities for students once they arrived in college.

2.3.1 Importance of Experiential Learning

Vygotsky believed that children absorb more through actual experiences (Mooney, 2000). Vygotsky (1986) also stated that the child's view is overwhelmingly predisposed by the views of others. This collaboration with adults expands the child's learning or the building of knowledge. Vygotsky additionally emphasized the importance of teamwork and communication to expand the skills and knowledge of a child (Mooney, 2000).

Researchers Adams, Bruning, and Genalo (2000) conducted research focused on the importance of engineering in the K-12 curriculum. Adams et al. (2000) emphasized that the concepts of engineering (e.g., critical thinking and problem-solving) come naturally to a child. As a significant component of STEM, critical thinking should also be introduced to children as early as possible (Dean & Kuhn, 2003). As Jeffers, Safferman, and Safferman (2004) argue, "The study of engineering through hands-on, minds-on activities can help students develop these [exploration] skills" (p. 5). In the context of this same study by Jeffers et al. (2004), opportunities that mentors have with students in an informal environment could have a powerful influence on the cognitive growth of students (Hofstein & Rosenfeld, 1996). This study highlights the importance of such work for the students and provides them with other positive influences from mentors that are outside the classroom.

2.3.2 Synthesis

Vygotsky offered critical examination to show student's collaboration with mentors to help understand the world around them and to develop knowledge and practical skills. A mentor can offer direction and guidance for students (Larson, 2006) as the development was explained in Vygotsky's zone of proximal development. The direction and guidance from a mentor can encourage openness and promote intellectual growth (Dubois & Rhodes, 2006). The theoretical framework proposed above seeks to clarify the importance of mentor programs in STEM elementary programs by exploring the concepts of these engineering experiences to develop in-depth experiential learning. This dissertation acknowledges the importance of the findings for future mentors when choosing programs to participate.

2.4 Summary

The purpose of this study is to examine the involvement of mentors to help teach elementary students STEM skills that may impact their lives. This study takes the importance of informal mentoring seriously and addresses a need for continued research of informal mentoring in STEM for elementary students. All sectors must offer skill growth, that should start in earlier in the education (Jacobs, 2010). P21 (2009) promotes more accountability for practical skills such as problem-solving, critical thinking, teamwork, and communication. The examination of Vygotsky delivers support of humanity, through the collaboration for understanding workplace skills. Mentoring elementary school students in the context of afterschool robotics programs connect the concepts learned with their hands-on application, while potentially increasing interest in STEM fields.

3. METHODOLOGY

3.1 Introduction

This chapter defines the proposed study, an explanation of the research design, and the study setting. This chapter also explains details about research protocols and procedures in the enrollment of the participants. The procedures for collecting participant data through interviews, observations, and documents are also comprised in Chapter 3. Since younger participants were included, moral situations are also addressed. Lastly, specific measures for the analysis of data that aim to explain the proposed research question.

3.2 Research Question

This research explores the participation of mentors in informal elementary STEM programs. The central research question for the study is:

> How do mentors impact student participants' advancement of specific engineering skills, including problem-solving, critical thinking, teamwork, and communication?

As the four main skill components of STEM skills build upon teamwork and problem-solving, it was important to focus the research on a theory that would support the exchange of ideas and knowledge through shared experiences. The research philosophy for this study is social constructivism. Lynch (2016) emphasized that the key feature of social constructivism in education are shared experiences that are the result of exploration, investigation, and social interaction. One of the main concepts of social constructivism is that knowledge is constructed via interactions with others. As the focus of STEM education involves problem-solving, critical thinking, communication, and teamwork, which in turn often involve learning through interaction, the social constructivist philosophy is relevant to this study. Mertens (2008) additionally argues that qualitative methodology is vital for research that includes an exchange of knowledge. He adds that one possible methodology for quality qualitative research could be rooted in social constructivism. Vygotsky (1978) explained that students learn from others inside a system (social constructivism). An active learning environment allows participants to engage in skills where knowledge is seen as the ability to problem-solve and carry out tasks (Collins, Brown, Newman, & Resnick, 1989). This framework aligns with the philosophy of social constructivism as active learning environments allow students to engage and exchange ideas and knowledge with others and develop their skills.

3.3 Research Design

The qualitative research that formed the central focus of this dissertation was a collective case study of mentor-led robotics programs in the U.S. state of Indiana. A qualitative research design was an appropriate approach to this study, as defined by Creswell (1998):

> Qualitative research is an inquiry process of understanding based on distinct methodological traditions of inquiry that explore a social or human problem. The researcher builds a complex, holistic picture, analyzes words; reports detailed views of participants; and conducts the study in a natural setting. (p. 15)

Additionally, a case study is an investigation of a constrained network or a case (or multiple cases) completed by comprehensive data collection, including multiple sources (Creswell & Poth, 2017). Case studies are also used to discover topics and concepts when a "why" or "how" question is of concern (Yin, 2017). In addition, case study research is advantageous when trying to discover a phenomenon (such as mentoring and program effectiveness) and understanding the setting in which the phenomenon is occurring (Creswell & Poth, 2017). The researcher in this study intended to discover and better understand the phenomenon of how mentors can impact students' STEM knowledge and skills through afterschool robotics programs.

A collective case study approach was selected since a single phenomenon of interest was the focus of this research, and multiple cases were used to explore the issue (Creswell, 2013). The collective case study consists of several cases to examine a "phenomenon, population, or general condition" (Stake, 2000, p. 437). The issue of mentor involvement in an informal STEM program was a suitable way to frame each case around skill development. This method was carefully chosen because this type of case study design is particularly appropriate to study the multifaceted phenomena in which the variables being studied cannot be entirely disconnected from the setting in which they exist (Yin, 2017).

Analyses within each program were undertaken to illuminate patterns and increase the potential for generalizing beyond particular cases (Yin, 2017). The purpose of the within-case analysis was to draw connections among the unique perspectives of each participant inside each case. During the data analysis process, themes were developed by "layering the analysis" (Creswell

& Poth, 2017), first by showing unique situations of each participant, followed by grouping by the program of these unique situations into comprehensive groupings.

3.4 Research Setting/Context

Within the context of the SRI (State Robotics Initiative) robotics program, described in more detail below, the experiences of the participants were examined on a case basis pre-competition, during competitions, and post-competition. A primary emphasis within collective case studies is the classification of the experiences, or the phenomenon, within the various individual situations (Stake, 2013). Each case was analyzed independently, followed by a within-case analysis that enables a broader depiction within each program, demonstrative of the involvement among mentor-student relationships in each specific program.

3.4.1 Participants

The researcher searched for possible participants by asking for guidance from TechPoint, a non-profit organization focusing on STEM education for elementary students, with an emphasis on coding and robotics. The TechPoint robotics program includes 17,418 elementary and middle school students from various schools in the U.S. state of Indiana (TechPoint, 2018). Background information about the participating schools revealed an assorted spread across academic and socioeconomic levels (TechPoint, 2018). In addition, a variety of schools had active participation in the TechPoint robotics program at the time of the study.

Purposeful sampling was used to enhance the selection and understanding of each case. McMillan and Schumacher (1997) described purposeful sampling as selecting specific cases that are rich in information for the study. TechPoint provided a list of all programs with mentors which was then narrowed down based on prerequisite criteria:

1. The mentor was currently an active mentor to an elementary robotics team. By being an active mentor of an elementary school robotics program, the mentor attended most, if not all, meetings.
2. The mentor had experience in STEM (e.g., teaching experience, engineer experience, science experience). By having experience in STEM, mentors had a baseline level to explain complex problems to the students.

3. The mentor had worked for more than one year with the SRI program. By having participated in robotics for more than a year, the mentor was knowledgeable about the robotics program.

3.4.2 Criteria for Elimination

The following were criteria for elimination for this study.

1. The program did not have an active mentor partnership outside of teachers, and/or
2. Students and mentors were unwilling to participate in research.

3.4.3 Research Sample and Data Sources

Three programs were selected in Indiana as the sites to investigate the impact of mentoring of specific STEM skills, namely problem-solving, critical thinking, teamwork, and communication, in robotics programs. This population of students had access to certain types of programs in different settings. However, there is little evidence of how mentors influence these populations, especially in rural settings. As described in more detail below, individual interviews with students and mentors, class observations of students and mentors, and related documents were collected for the study. The participants involved in this study signed all applicable forms (informed consent), which was mandatory by the Institutional Review Board (IRB), and all of the programs selected as cases were within a 50-mile radius of the researcher's university.

3.4.4 Ethical Considerations

Involvement was voluntary, and the participants could terminate involvement without negative consequences. Participants' identities were confidential, using pseudonyms and limiting availability to confidential data to only the researcher and the participant individually. The research design was explained to each participant, as well as to the parents of the elementary school students.

The participants were advised that no names of students, mentors (often referred to as coach by student teams), or the school or program name would not be explained in the final version of the study or any publications. The researcher obtained IRB approval from Purdue University before initial communication with participants to make sure participants were protected.

3.4.5 Biases of the Participants

The chosen mentor participants were those already involved with a voluntary after-school elementary robotics program in Indiana. The mentors were interviewed based on their voluntary involvement in the robotics program. Additionally, the participants agreed to participate in the study, which could represent a bias. For example, the involvement of the mentor could influence their positive responses as they want to give back to the school system and support their community. Additionally, the students involved in the robotics program have the most to gain in a STEM mentorship and probably spoke more favorably about the program.

3.4.6 Role of the Researcher

The researcher has had much experience as a STEM mentor in elementary and middle school settings. To help reduce the risk of manipulating the data collection and analysis with biases based on these prior experiences, the researcher utilized the triangulation of multiple data sources. For instance, one avenue employed was through the interviewing of mentors and students. The application of observation to confirm the link between identified actions and results was used as an extra minimization of the researcher's biases.

3.5 Data Collection Procedures

Three kinds of qualitative data – observations, interviews, and documents – served as the foundations for this study. Stake (2013) summarized that the most common methods of the case study are observation, interview, coding, data management, and interpretation. Because case studies rely on various sources (Yin, 2017), this study focused on two data sources (student and mentor) and three data methods (interviews, observations, documents). As part of the student interview process, the researcher also collected other information about the participants (Karp & Schneider, 2011), including gender, race/ethnicity, grade level, and prior experience with robotics.

3.5.1 Observations

The role of the researcher was primarily as an observer. The purpose of observations was to examine students' experiences, including how they engage with the STEM activities and mentors, as well as how mentors participate in STEM programs. The reason for including observations was to gather information on activities and connections *in situ* and in real-time (Rallis & Rossman, 2012). As Gray described, “Observation involves the systematic viewing of people’s actions and recording, analysis, and interpretation of their behavior” (Gray, 2013, p. 397). Observations were primarily descriptive, including pictures of the environment and final projects, with some reflective notes by the researcher regarding the alignment of observations over time (Hancock & Algozzine, 2016). The purpose of using observation in the case study design was for the investigation and to gain a better first-hand understanding of teams and relationships that might not be mentioned during interviews or in documents.

Observations were conducted approximately one to three times per week from February to May 2019. Each meeting varied from 50 to 90 minutes and included robot building and other team meeting activities. The researcher consulted each mentor to gain knowledge of each program. The researcher completed one observation each day and immediately set aside time to reflect on the observation and write initial notes. The initial observation was comprehensive and involved the detailed description of the actual location, participants, protocols, and illustrations of the space. The following observations focused on answering the study questions and disclosing the individual intricacies of each program (Stake, 1995). Interviews were conducted after observations to ask questions, understand interpretations of participants regarding various activities or events. The location of observations provided data that was received because of the real-life experiences. The recorded reflective notes were used with the interview transcriptions to understand data and ideas, including to clarify and refine the emergence of themes (Gray, 2013).

3.5.2 Interviews

Initially, group interviews were proposed to allow students to answer questions collaboratively. Stake (2013) and Hancock and Algozzine (2016) state that interviews of participants in groups can be beneficial because of group-thought and sharing of ideas. However, group interviews can be non-productive exchange. However, it was determined that group interviews not be conducted because of the importance of protecting the confidentiality of each student’s and mentor’s experience.

Single interviews were used to collect data in order to gather the information that may be inaccessible through observations (Bogdan & Biklen, 2011) and to gain a more in-depth understanding of each participant. After the selection of the participating programs, each mentor and student were interviewed, either in person or virtually. Interviews were conducted with students and mentors from each case site, and these were audio recorded. Insights gained from prior observations also helped frame the semi-structured interviews.

Semi-structured interview protocols were used to direct the conversation, but the researcher sometimes followed up with new questions that logically arose from the conversation (Bryman, 2017). For students, ground rules were used to assist children in providing accurate information during their interview (Danby, Brubacher, Sharman, & Powell, 2015). The interviews were recorded and transcribed verbatim. The first participant interview focused more on demographic information and to elicit each participant's philosophy, history, and background. The subsequent interviews centered on collecting additional data for the study. Eighteen students were interviewed across all programs, with each student interviewed at least twice (details in Table 5). All interviews took an average of 15-20 minutes to complete.

Every mentor, student, and student's parent or guardian was advised that participant involvement was optional and comprised of observations, three interviews (pre, Jan/Feb, during, Feb/March, and post, April/May competition), and access to design logs. All names of mentors and students were given pseudonyms following the interviews. The ID code was made up of the following: 1) program name, 2) team number, and 3) birthday. A pseudonym was then created for each participant during the analysis process.

Interview Question Development

The researcher's procedures for the interview question development included: asking a limited number of questions, permitting the student and mentor to lead the conversation, and asking questions to invite the participants to have a conversation. If additional questions arose after the initial interviews, supplementary questions were given. A sample format for the interviews is detailed in Tables 4 and 5 in the Appendix.

The research questions and the review of literature influenced the expansion of each interview question as well as consideration for the theoretical framework related to the zone of proximal development (how individuals arrange and structure the learning environment). Questions were identical except for the substitution of appropriate wording for each participant group.

To understand how knowledge of STEM skills gained from mentors impacts students (see Figure 3), the researcher developed a classification framework for the interviews corresponding with P21 (2011) STEM skills, as shown in Tables 1 and 2.

Table 1. Research objectives/ interview map for mentors

Research Objectives	**Pre-Competition Interview Question Number**	**During-Competition Interview Question Number**	**Post-Competition Interview Question Number**
Demographics	1, 2, 3, 4, 5, 6	1, 2	1, 2
Problem-solving (Troubleshooting)	7, 8, 9, 10	3, 4, 5, 6	3, 4
Critical Thinking (Information Literacy)	11, 12, 13, 14	7, 8, 9, 10	5, 6
Teamwork	15, 16, 17, 18	11, 12, 13, 14	7, 8, 9
Communication	19, 20	15, 16	10

Table 2. Research objectives/ interview map for students

Research Objectives	**Pre-Competition Interview Question Number**	**During-Competition Interview Question Number**	**Post-Competition Interview Question Number**
Demographics	1, 2, 3, 4, 5	1, 2, 3	1, 2
Problem-Solving (Troubleshooting)	6, 7, 8, 9, 10, 11	4, 5, 6, 7, 8, 9	3, 4
Critical Thinking (Information Literacy)	12, 13, 14, 15	10, 11, 12, 13	5, 6
Teamwork	16, 17, 18, 19, 20, 21, 22, 23	14, 15, 16, 17, 18, 19, 20, 21,	7, 8, 9
Communication	24, 25	22, 23	10
Mentor Impact	26, 27, 28, 29	24	11

3.5.3 Documents

One primary form of documentation that was collected and analyzed for this study was the engineering notebook. The engineering notebook is a method for student teams to understand the engineering design process better while also using critical life skills, including problem-solving, critical thinking, teamwork, and communication. Each engineering notebook is formed through a concentrated effort to document design choices. The engineering notebook was selected as a way to triangulate across the data set (Hancock & Algozzine, 2016). The researcher copied or photographed documents to clarify meaning if the student or mentor mentioned the notebook that was created by the student.

3.6 Data Collection

Since elementary students were involved, data collection and the timing of conduction was critical. The access to students in the summer was restricted, which led to the research to be conducted throughout the school year. Because of the students' youth, parental consent was required before data collection could begin. The researcher contacted the Director of Robotics at TechPoint to help advertise the study. Next, the researcher contacted the robotics mentors at each program to describe the significance of such research and how it could assist TechPoint.

Data were collected from February 2019 to May 2019 at three individual program sites. The collection of data was created to gain an in-depth understanding of the intricacies of each case. Table A.2 (see Appendix A) details the research schedule.

TechPoint has two robotics seasons, one in the fall semester and one in the spring. The schedule was designed to occur within the TechPoint spring semester to permit the researcher to contact the mentors and students. The robot build is six weeks long, with state competitions in March. By collecting data during the February to May season, access to observe and interview mentors and students was most feasible. Careful coordination with the mentors and TechPoint was essential in collecting data.

3.6.1 Human Subjects Considerations

The researcher coordinated with Indiana mentors and the TechPoint director from September through December to publicize and pursue involvement for the study. The following incentives were offered to participants:

- $20 Amazon gift card for mentors, and
- The children's book, *The World Is So Wide*, $18 retail value, given to students.

The study was submitted to Purdue University's IRB to receive approval to research human individuals. The application to the IRB comprised of multiple items: 1) comprehensive research protocols, 2) explanation of the population, 3) copy of interview questions, 4) information letter for students and parents, 5) consent form for parents, and 6) consent form for students. Also, an explanation of consent for gaining access, as well as the number, length, location of interviews of all interactions with mentors and students.

There were no identified risks with the students participating; however, other forms, like permission, were required for minors. After approval of the IRB, the study was begun by the researcher. All correspondence was defined: 1) the research's purpose, 2) risks, 3) benefits, and 4) confidentiality. In addition to the form of permission, parents received a phone number to receive spoken instructions. Data regarding demographics comprised of specifics needed to characterize the research but not to allow the identification of individuals. Documentation related to the IRB approval is provided in the Appendix.

3.7 Data Analysis

3.7.1 Coding

Coding decisions were made based on the methodological needs of the study. The researcher used elemental methods for the first cycle of coding, which, according to Saldaña (2015), "consist of foundation approaches to coding qualitative texts" (p. 80). Elemental methods offer both primary and focus filters to assist in the foundation of future coding cycles. The elemental method used was in vivo coding. In vivo coding uses verbatim quotes directly from the data (Saldaña, 2015). The researcher chose in vivo coding as it can highlight participant-generated words in their language to give additional meaning. For this study, Nvivo coding was used as a tool to accomplish elemental coding. Nvivo (version 12), a software application designed for qualitative research, was the primary data analysis tool. Interview transcripts, observation notes, and documents were imported into the software. The recorded interviews were also used through the analysis progression. From the finished transcripts, an analysis of the content of the data was performed. A comprehensive investigation was carried out, which is vital at the commencement of the study to aid in the generation of coding with their associated categories. This analysis also exposed the possible associations among the categories (Bogdan & Biklen, 2011; Creswell & Poth, 2017). Codes were recognized through this process. Codes were usually a word or phrase that embodied the essence of a limited amount of text. While reading, a code or multiple codes related to the research question were selected and applied to the data sources. The researcher gave one or more codes to help categorize the data and permit the organization of more in-depth analysis later on.

The researcher then completed the second cycle of coding, which gave the researcher a more advanced way of reorganizing and reanalyzing the data coded through the first coding cycle. Nvivo also allowed the ability to write notes in conjunction with each excerpt. First, text codes were identified. The text codes were clustered by similar meaning and labeled by the cluster's holistic meaning. The second cycle of coding involved the use of a pattern coding logic to group summaries into a small number of constructs (Saldaña, 2015). As Miles and Huberman (1994) explain, pattern coding involves

> explanatory or inferential codes, ones that identify an emergent theme, configuration, or explanation. They pull together a lot of material into a more meaningful and parsimonious unit of analysis. They are sort of a meta-code. Pattern Coding is a way of grouping those summaries into a smaller number of sets, themes, or constructs. (p. 69)

As perceptions start to show, the method of the assembly into themes occurs. The classification aids in outlining perceptions into broader explanations with subthemes from the data. By searching for patterns, critical situations for each participant were recognized.

After the second cycle of coding, code weaving took place. Code weaving is the actual integration of phrases into a narrative to see and make sense of the larger picture, thus working toward addressing the research question (Saldaña, 2015). An analysis within each program was undertaken to illuminate patterns and increase the potential for generalizing beyond particular cases (Yin, 2017). The purpose of the within-case analysis was to show associations with universal themes of each case. While coding, the researcher looked for answers to detailed questions in the data and results, such as why, when, where, how, and with what. Answers to these questions helped to uncover relationships among themes. During the data analysis process, themes were developed by “layering the analysis” (Creswell & Poth, 2017), first by showing unique situations of each participant, followed by grouping by the program of these unique situations into comprehensive groupings.

This final step involved organizing a description of the themes that draw attention and are usually shaped when describing an event by interviewees (Creswell & Poth, 2017). This technique takes the information found during the interviews and combines them to be compared with the research questions to frame a concept. Stake (1995) called this process of progressive focusing.

Table 3 shows a coding example of responses.

Table 3. Coding Example of Responses

Speaker	**Response**	**Code**	**Subtheme**
Researcher:	How does your coach help you solve problems in robotics?		
Student:	Um, they give us lots of support. So if we're, if we're struggling something, *they might suggest what we could do*. They might, *they're not going to tell us what we should do, but they might suggest something*. Yeah. But we should do. So *they might say instead of having these wheels switched in that for others wheels*	Problem-Solving	Problem recognition
Researcher:	When facing a problem, how did your coach help you to decide which answers the best answer?		
Student:	Um, so, um, *if we're struggling and about what we have already tried, and we tell them, and they're like, well what's something that kind of that's like, like there may be something that works with the plan but it doesn't, but the plan doesn't work overall. So (they) might tell us like what works and then you could tie that into whatever else you're doing*. So, uh, *my team, you're talking about a garden in space because we didn't want people to just be eating the same food over and over again, but we need to make sure that the food had enough calories. So we, we didn't know how much to grow. And so we*	Problem-Solving	Explanation Refinement

Table 3 continued

Speaker	Response	Code	Subtheme
	figured out how many people are you going to have on a spaceship? And then how many calories does each fruit or vegetable have? And then that determines how much you're getting any [inaudible] [inaudible]		
Researcher:	And then how does your coach help you? To make sure an Idea is important?		
Student:	MMM. If they, they, *they say if we do it and we are kind of close to it, but we're not really, then they can say, well you were really close, so maybe you could keep trying that and tweaking a little bit*	Critical Thinking	Structure reasoning
Researcher:	And then, how does your coach help you to make sure that the information is correct?		
Student:	Um, well we, um, *we brought in some people to help us with the information and so, um, the coaches, they brought in some people and the people they knew like what was correct, like with vegetables like gardeners and so they can back up our information*.	Critical Thinking	Argument Evaluation
Researcher:	Yep. And how has your coach, uh, has your coach help you learn what it means to be a good team member?		
Student:	Um, *like if somebody feels left out, they usually call the team over, and they give a talk, and you're like, this person is being left out, and we should give them more support. Or if one person's doing it all or if there's one person who's not working, then he might call them over and say, or they might call them over and say like, you need to start working because what you do affects the team because they're down one person*.	Teamwork	Inclusion
Researcher:	And how has your coach helped you learn how to solve disagreements between your team members?		

Table 3 continued

Speaker	Response	Code	Subtheme
Student:	Um, *if we're arguing, they might tell us that it's like, no, like just kinda calm down and try and compromise with it or try one idea and then try the other and see which one looks better*.	Teamwork	Conflict Resolution
Researcher:	That's great. Has your coach ever helped you present in robotics? Like, help you practice?		
Student:	Uh, yeah, *helped us practice. So like they'll sit there and then our group will come up and well present their poster like we would do the judges in. That kind of prepares us*.	Communication	Feedback

Analysis of data included writing up a comprehensive portrayal of each case (Creswell & Poth, 2017). The researcher collected extensive data to analyze a general and fixed scope of each case. An important aspect of this research is identifying the data that accurately represents the phenomena of interest. The interviews portrayed the characteristics of effective mentor-student relationships and, more specifically, concerning developing the four P21 skills: problem-solving, critical thinking, teamwork, and communication.

After finalizing the analysis in Nvivo, excerpts were copied and combined with codes and notes into a Microsoft Excel spreadsheet for analysis, including categorization, clarifying, and further theme expansion. Data were analyzed to explore themes that were relevant to the research question (mentoring and impact on students), and data were analyzed to identify a potential theory (e.g., mentoring in STEM is effective in growth in problem-solving). This process was beneficial for forming the selections into themes and in formulating a framework for writing.

To understand how knowledge of STEM skills gained from mentors impacts students, the researcher focused on a coding scheme to correspond with P21 (2011) STEM that can be viewed in Tables 6 and 7 (see Appendix). This coding scheme explains how, with the assistance of a mentor, students develop skills to explain the further goal of understanding.

3.8 Ensuring Quality of the Research Data

Validity is the point in which research replicates or evaluates the notion to be measured (Moskal, Leydens, & Pavelich, 2002). Walther, Sochacka, and Kellam (2013) noted that in engineering education research studies, the quality of data could be categorized into five validation constructs and process reliability. Following these validation categories can help ensure the quality of the research data. The validation categories are theoretical, procedural, communicative, pragmatic, and ethical. This approach to evaluating the quality of a study considers whether the research is based in theory, follows a procedure, is effectively communicated, has practical relevance, and follows ethical procedures and practices. Additionally, process reliability involves the researcher being conscious of influences that can be mitigated through reflection.

The patterns found in this study were compared with definitions defined before the study by 21st Century Skills and other literature, as reviewed in Chapter 2. As only three programs were observed, results are not generalizable but can be seen as potentially transferable. The examples from the cases in this study can be used so that other informal programs can learn new approaches. The data collected, interviews, observations, and field notes were directed through the lens of published literature. In addition, to maintain validity throughout data collection, the interview questions were both open and closed-ended to acquire data in a variety of options (Myers, 2009). The combination of various types of data (interviews, observations, and engineering notebooks) provides multiple options to reinforce validity internally (Zohrabi, 2013).

Following each interview, journal entries (content logs) recorded the researcher’s perceptions of those interviewed to reduce the possibility of the introduction of bias into the transcription and analysis of the interviews. A colleague was then be asked to read over the journal entries before analysis to make sure that the comments were not indicative of bias on the part of the researcher.

In addition, the researcher checked transcriptions from the taped interviews to ensure accuracy. Next, the researcher coded transcripts to search for emergent themes, as described in more detail below. This procedure was iterated several times. The researcher wrote notes regarding the codes and coding process to ensure consistency. NVivo was used to code the data, and pattern coding was completed to determine the codes that occurred most frequently.

Member checking confirmed that the reliability is sustained at each step during the research process. The actual names of mentors were not released. After the transcripts were verified, the method of recognizing commonalities among the participants commenced. As noted above, Tables 5 and 6 in the Appendix map the interview questions with research objectives.

3.8.1 Triangulation

Triangulation was also used to strengthen the quality of the analysis and the findings generated through the analysis. Stake (2013) defined triangulation as a method of repetitive data assembly and extensive analysis of information. Patton (2014) discussed three forms of triangulation in completing an assessment or investigation, including sources of data, perspectives on the same data set, and varying methods. For this study, triangulation was created in a variety of ways. The first involved interviewing through two points of participants – students and mentors. Another was through interviews of the various members, including documentation. Using multiple sites is also a form of triangulation as information from the different sites could be compared for commonalities. Lastly, biases were resolved by member checking and content logs with those who were interviewed. The application of observation to confirm the link between identified actions was used as a further explanation of reducing the biases of the researcher. The merging of information among these types of triangulation enabled higher reliability and internal validity of patterns gained from the data. Each process increased the level of reliability of the study.

3.9 Summary

Chapter 3 defined the methodology used to define and qualify the development of the P21 STEM skills between mentors and students. A collective case study was used, with three diverse programs, with multiple modes of data collection (observation, interviews, and documents). This chapter also described the research question, research design, protocol, and measures associated with the enrollment of study participants. The actions for accumulating data of the participants were comprised in this chapter, including related validity and reliability considerations, and moral issues concerning the study of elementary school students were identified. The analysis of data progression summarized above-involved pattern coding that establishes the advancement of specific engineering skills.

4. FINDINGS

The purpose of this collective case study was to explore the future for mentor involvement in informal STEM programs as motivations to answer the following question: How do mentors impact student participants' advancement of specific engineering skills, including problem-solving, critical thinking, teamwork, and communication?

Concerning research methodologies and data analysis, a within-case analysis was used to draw connections among themes of programs and to share the essential findings from the different programs. NVivo was the primary analysis tool. As described in more detail above, Information from the interview transcripts, observation notes, and documents were imported into the NVivo software, and a content analysis was conducted. Two cycles of coding were performed as concepts began to surface into themes that could be grouped and classified. A layering of analyses (Creswell & Poth, 2017) was used to identify themes. Each of the three sections in this chapter includes more information on the specific steps used for data analysis.

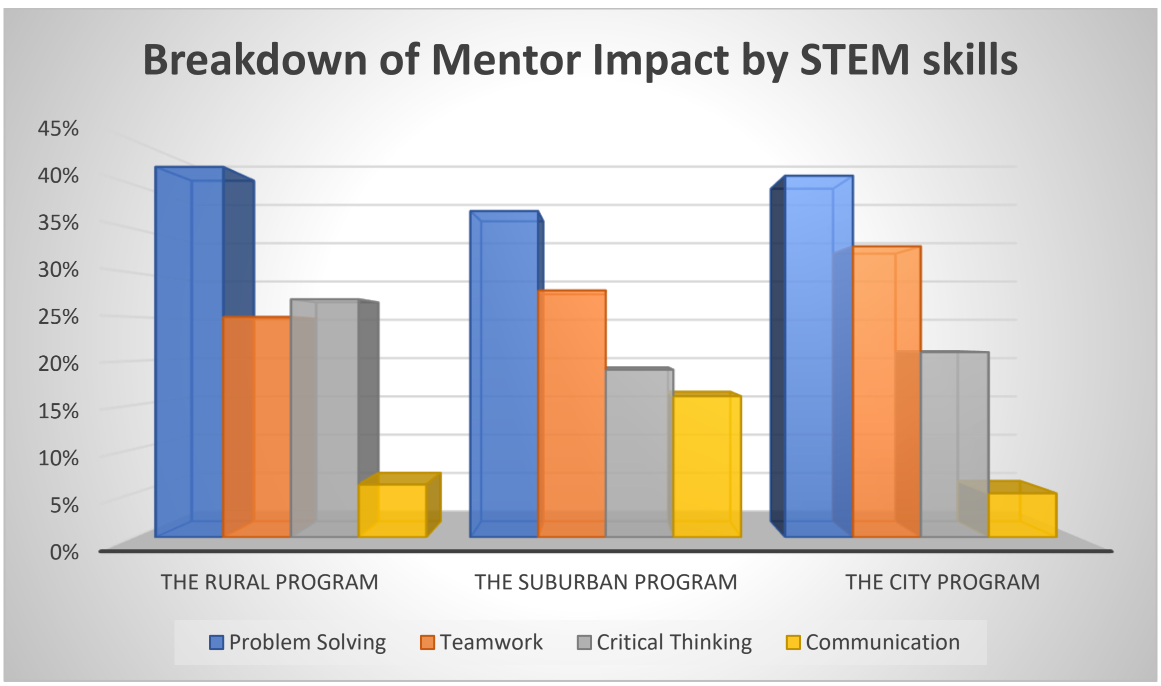

Figure 3. Breakdown of mentor impact of STEM skills.

Even though the results were not cross-case analyzed, all programs had mentors who sought to increase knowledge with the students even though each program had a different background and reason for starting the robotics program. In addition, each program had very different demographics and styles, but all showed the integration of STEM and robotics in an afterschool program, with emphasis on problem-solving. Across all three programs, the STEM skill problem-solving (see Figure 3) was an area where mentors impacted students the most. In particular, mentors helped students process appropriate explanations for why a situation was happening (see Table 4). Other STEM skills researched were also observed but less frequently: critical thinking, teamwork, and communication. These were found in all three programs.

4.1 Description of the Robotics' Programs

There are a variety of robotics program options available to system educators. However, this research focused on two specific types of robotics programs: Vex and Foundations for Inspiration and Recognition in Science and Technology (FIRST) Lego League. Both versions use a programmable robot. The Vex Robotics program is the largest in the world, with Vex IQ being a subset for elementary and middle school students. The Vex Robotics program provides hands-on learning by encouraging problem-solving, teamwork, and communication skills (Vex Robotics, 2019). The base Vex robotics kit includes approximately 600 structural components. The Vex IQ robotics kit also includes plastic pieces, "robot brain" and sensors. The "robot brain" has input and output ports as well as a robot port to allow the robot to be driven by remote control. As a team, elementary students then use the software, some already preloaded, to program the robot that they design. Every year students are given a research project to research and solve a challenge as well as design, create, program, and drive a robot in qualifying competitions. Teams, in turn, have opportunities to compete in state-level championships, followed by an annual World Championship event in Louisville, Kentucky.

Table 4. Prevalence of STEM skill themes by category and case

STEM skill categories and themes	The Rural Program	The Suburban Program	The City Program
Problem-Solving			
Mentor helps student process appropriate explanation(s)	63%	47%	74%
Mentor helps student recognize problem(s)	25%	33%	12%
Mentor helps student refine the explanation(s)	22%	20%	14%
Critical Thinking			
Mentor helps student evaluate argument(s)	40%	25%	29%
Mentor helps student structure reasoning	30%	12.5%	24%
Mentor helps student communicate conclusion(s)	20%	12.5%	n/a
Mentor helps student assess assumption(s)	10%	50%	47%
Teamwork			
Mentor helps the student with conflict resolution	45%	8%	38%
Mentor helps the student improve the team by inclusion techniques	33%	75%	45%
Mentor helps student communicate with each other	22%	17%	17%
Communication			
Mentor helps student decode intended meaning	50%	14%	25%
Mentor helps the student by giving feedback	50%	86%	50%
Mentor helps student generate ideas based on the intended meaning	n/a	n/a	25%

FIRST Lego League is also a global competition for elementary and middle school students. The FIRST Lego League is “designed to get children excited about science and technology and teach them valuable employment and life skills” (FIRST LEGO League, 2019). The LEGO Mindstorms robotics kit consists of LEGO bricks that can be used to design custom robots. The robotic kits also consist of motors, gears, and sensors, which can be automated. The standard robotics kit includes instructions for building wheeled and manipulated robots. The robotics program may differ from location to location. However, there are many components that are common to the program as both intend to enhance STEM skills through active learning. Every year, the FIRST Lego League launches a specific real-world challenge for each student team to research so they can design, create, and program this is different from the Vex competition. Both programs typically begin with preparation and practice of about three months, and this process eventually will lead up to attending competitions. The objective is for teams to qualify in events for research are state or world championship events. Table 5 presents an additional comparison of the programs:

Table 5. Robotic assembly kit comparison

Name	**Mindstorm**	**VEX IQ**
Company	LEGO	Vex Robotics
Sensors	Speaker, motion, distance, bump, color, encoders, three motors	Speaker, motion, distance, color, two bumpers, four motors, joystick, gyroscope, radio
Batteries	Replaceable alkaline	Rechargeable
Connection Capabilities	Bluetooth, Universal Serial Bus, radio	Bluetooth, Universal Serial Bus
Additional Attachments	Gyroscope	All direction wheels, tank chain tread
Standard Robotics Kit Cost	$350	$330

In both versions, a competition field is used. The competition field is a plastic surface and frame that the robots navigate and compete on. All programs studied had practice competition fields that were replicas of competition fields used during competition. A picture of a robotics board from the Vex IQ program can be seen in Figure 4.

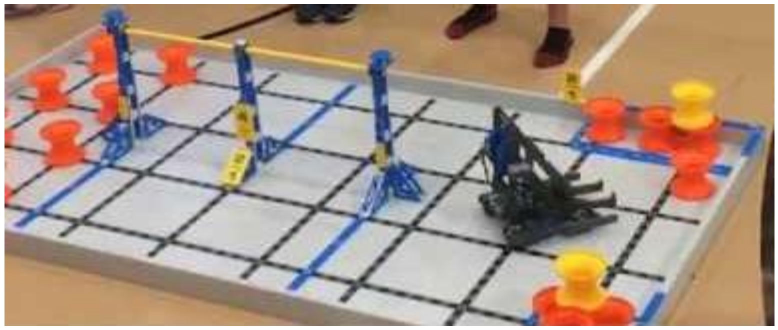

Figure 4. Vex IQ competition field with barriers and a robot.

Teams are also formed within each program. The teams vary in size, depending on enrollment in the program. Teams can be co-ed, all boys, or all girls. Some schools offer a choice where other schools may only offer gender-specific teams. Some programs have enough participants to assign specific roles to individual students; other programs may have students rotate roles within the team. Mentors run the programs and may include school staff and/or volunteers from the parents and community. Many programs will encourage a theme to work with to encourage teamwork and enthusiasm. The theme is usually created by the students with guidance from the mentors if needed. A more detailed description of the three robotics programs that serve as cases for this study is provided below and also summarized in Table 6.

4.1.1 Program #1

This robotics program was located in northcentral Indiana. The program was in a rural community with a population of 6,200 people. This program was situated in a school district with 800 students, grades kindergarten to twelve, all housed in one school building. The school district was committed to high-tech preparation with confidence. Since it is a smaller district, the community raises money from many different sources, including local businesses, for its robotics programs.

Table 6. Description of the robotics programs

Description of the Program	**Type of Robotics**	**Progra m Size**	**Grades involved**	**Progra m Type**	**Number of Mentors**	**Number of Teams**	**Data Sources**
Program #1	Vex IQ	28 students (5 girls; 23 boys)	5-6th grade	Rural	3	4	Two mentors and four student interviews; observations; design journals
Program #2	First Lego League	31 students (18 girls; 13 boys)	5th grade	Suburba n	3	4	Three mentors and seven student interviews; observations; design journals
Program #3	Vex IQ	16 students (8 girls; 8 boys)	4-5th grade	City	3	2	Three mentors and seven student interviews; observations; design journals

The robotics program is housed in a separate classroom in the elementary wing of the school. Upon entering the class, there are two practice competition fields on the floor with tables on the outside to program the robot using various laptops. Because of the separate robotics room, the equipment and practice competition fields are kept in place year-round for students, including the summer. At the beginning of the school year, a call-out for robotics is given by the coaches. The program is supervised by two lead coaches (mentors): one, a teacher, who handles administrative responsibilities (registration for tournaments and the fundraisers), and the other, an executive and engineer at a local manufacturing company, who handles all programming and robotic involvement. Both mentors are from the area and are active members of other programs at the school. There is also one other mentor from a local engineering company that comes at least once a week. This robotics program meets twice during the week with practices before (for an hour) and after school (for approximately ninety minutes). Twenty-eight students make up the robotics program, which includes five girls and 23 boys.

4.1.2 Program #2

The second robotics program was located in a suburb in west Indiana. It is in an area with a Research I university and a population of about 75,000. This school district has eleven elementary schools. The elementary school visited serves 450 students in grades kindergarten through fifth grade. The elementary school implemented Steven Covey's 7 Habits for Highly Effective People as an outline to encourage workplace skills with the expectation of producing well-rounded students for the 21st century.

The robotics program is located within a fifth-grade classroom, which serves as a place for coding, and a separate room is used for robotics practices. The same teacher who teaches fifth grade in the classroom during the day is the advisor of the program. At the beginning of the school year, a call-out for robotics is given to fifth-grade students only. The co-ed robotics team meets on separate days (18 girls on Wednesday and 13 boys on Tuesday) for an hour and thus is organized around separate girl's teams and boy's teams. The program is supervised by a lead mentor who started the robotics program six years ago. The lead mentor is a mechanical engineer at a construction equipment manufacturer who has two assistant mentors who also work as engineers at the same manufacturer.

4.1.3 Program #3

The last program is in an elementary school that serves 800 students in the city of Indianapolis. The school district serves more than 16,000 students. The school district has 11 elementary schools (first through sixth grades) and four early learning centers (kindergarten). According to their website, the elementary school also implemented Steven Covey's 7 Habits for Highly Effective People to help students find their path while inspiring others. One of the goals of the school is to create 21st-century experiences to generate leaders for the global community. In addition, the district encourages students to use critical thinking skills and the ability to self-direct their learning.

The robotics program is located within the media center in the elementary school. The students start each meeting with announcements and team assignments of coding, testing, research, and development. The coding and research and development students work on desktop computers in the corner of the media center while testing students work in a separate media center space that houses a practice competition field. At the beginning of the school year, try-outs for robotics begin and includes an interview process. The mentors work to make sure the teams are diverse and have a breadth of skills, highlighting the STEM skills of critical thinking, problem-solving, communication, and teamwork. The program is supervised by three mentors, all with equal responsibility. One of the mentors is a media specialist who is in charge of the media center, the second is a fourth-grade teacher with a mechanical engineering background, and the last mentor is a mother of one of the robotics students who has a chemical engineering background. The robotics program meets for two hours after school once a week. The program is made up of 16 students, eight girls, and eight boys.

It is important to note that both robotic programs do not come with specific instructions or guidelines for mentors or educators on how to teach and support the four main STEM skills. The curriculum may include guidelines for competition (formal policies and procedures); however, STEM skills are taught and reinforced through individual mentor support (informal lessons). STEM skills are important to the success of the student teams. Hence informal support from mentors and educators is essential. Mentors help close the gap among what is educated in school to students and hat is required to succeed in working with a team.

An example of how the four STEM skills can be linked to Robotics criteria can be seen in Table 7.

4.1.4 Research Questions

The question that guided this study was, “How do mentors impact student participants’ advancement of specific engineering skills, including problem-solving, critical thinking, teamwork, and communication?”

By breaking down the question into parts by STEM skills, the researcher will answer the main guiding question. The following sections present findings based on the four skills of STEM.

Table 7. STEM skills linked to Robotics Criteria

21 Century Skill Observed	First Lego League Criteria	Vex Robotics Criteria
Problem-Solving: Although there are many styles and types of problem-solving techniques, for this study, the style of problem-solving reflects the teachings that are commonly seen in STEM education. More specifically, problem-solving is the ability and skill to unravel different situations that are unfamiliar and to make decisions about the best sequence of action through creativity, collaboration, or resourcefulness (P21, 2009).	"Effectiveness: problem-solving and decision-making processes help the team achieve its goals" (First Lego League, 2020). Solution Development: "Systematic process used to select, develop, evaluate, test, and improve the solution" (First Lego League, 2020).	Test and Redesign "captures the key results of the troubleshooting, testing, and redesign cycle" (Vex, 2020).
Critical Thinking: A P21 Learning and Innovation Skill that involves "purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation…upon which judgement is based" (Facione, 1990, p. 3).	Problem Analysis: depth of "which the program was studied and analyzed by the team, including the extent of analysis of existing solutions" (First Lego League, 2020). "Design Process: ability to develop and explain improvement cycles where alternatives are considered and narrowed, selections tested, designs improved" (First Lego League, 2020).	Brainstorming: "provides an extensive list of possible approaches to the challenge" (Vex, 2020).
Teamwork: A skill that includes the expertise that involves "interaction between two or more individuals working together to solve problems" effectively (NCREL & Metiri Group, 2003, p. 47).	"Team Solution: Clear explanation of the proposed solution and description of how it solves the problem" (First Lego League, 2020). "Team Spirit: enthusiastic and fun expression of the team identity" (First Lego League, 2020). Inclusion: "consideration and appreciation for the contributions (ideas and skills) of all team members, with balanced involvement" (First Lego League, 2020). "Respect: team members act and speak with integrity, so others feel valued--especially when solving problems or resolving conflicts" (First Lego League, 2020).	Teamwork: "shows that all team members' were involved in the process, that team members could be counted on because they did what they were supposed to and that the whole team shared ideas and supported the ideas of others" (Vex, 2020).

Table 7 continued

Communication: A P21 Learning and Innovation Skill that students demonstrate through expression using various exchanges of information by way of various tools, transmissions, and methods (NCREL & Metiri Group, 2003).	"Sharing: Degree to which the team shared their Project before the tournament with others who might benefit from the team's efforts" (First Lego League, 2020). "Mission Strategy: ability to clearly define and describe the team's game strategy" (First Lego League, 2020). "Presentation Effectiveness: Message delivery and organization of the presentation" (First Lego League, 2020).	"Select Approach explains why the selected approach was chosen" (Vex, 2020)

4.2 Relating the Cases to the Coding Scheme

After analyzing the data for critical issues and key points using the layering analysis (Creswell & Poth, 2017), a within-case grouping of the issues and key points were conducted that included broader and more abstract categories. Codes that were identified as program-specific were then analyzed for overall critical and key components. A codebook for themes that were specific to the impact of a mentor on STEM skills was organized for presentation. To understand how knowledge of STEM skills gained from mentors impacts students (see Figure 3), the researcher focused on a coding scheme to correspond with P21 (2011) STEM skills that can be viewed in Table 8. Table 8 identifies the main themes of the program.

The coding scheme that guided the three case studies were based on the 21st-Century Skills Map (P21, 2011) and research by Ehsan et al. (2018) and Crismond and Adams (2012). Using pattern coding logic (Chowdhury, 2015; Saldaña, 2015), it was discovered that many essential parts were existing throughout each case. Figure 3 presents a breakdown of mentor impact by the location of the STEM program. The findings in this step represent the last step of the layering analysis process conducted. Themes that emerged within the NVivo coding process led to the final analysis step, a set of dimensional themes were identified. The following sections present findings based on the organization of themes. Findings are presented for each STEM skills, and within each skill, a summary of the ways mentors supported the STEM skills are presented, followed by findings by location: rural, suburban, and city. Analyses within each program were undertaken to illuminate patterns and increase the potential for generalizing beyond particular cases (Yin, 2017).

The purpose of the within-case analysis was to draw connections among the unique perspectives of each participant inside each case.

The researcher studied three robotics programs from various areas in the state of Indiana. The researcher followed these three robotics teams at their location, and to their competitions. One program was located in a rural environment, the second was located in a suburban environment, and the third was located in a city environment. The results described are shown in three sections. The first section presents demographical information for the participants, the second section presents qualitative discoveries addressing the research questions, and the last section offers a summary of the main findings.

Table 8. Interview codebook of mentor impact on students of critical STEM skills

	Skill Criteria	Code	Actions
Understanding the mentoring impact on Students	1. Problem-Solving (Troubleshooting)	Problem-Solving: Although there are many styles and types of problem-solving techniques, for this study, the style of problem-solving reflects the teachings that are commonly seen in STEM education. More specifically, problem-solving is the ability and skill to unravel different situations that are unfamiliar and to make decisions about the best sequence of action through creativity, collaboration, or resourcefulness (P21, 2009).	• The student describes how the mentor assisted in the actual diagnosis • Student offers evidence in how mentor was involved in proposing new ways • The student uses trial and error at the request of the mentor to assist • The student uses a systematic design approach at the assistance of the mentor • The student describes essential concepts that the mentor explained to address knowledge gaps • The student describes how the mentor poses multiple options
	2. Critical Thinking (Information Literacy)	Critical Thinking: A P21 Learning and Innovation Skill that involves “purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation…upon which judgement is based” (Facione, 1990, p. 3).	• The student indicates an awareness of mentor involvement in thinking moreover, the reflection process • Student provides evidence of how mentor involvement helped make decisions, evaluate, and/or problem-solve • The student uses reason and/or reflection skills to create a strategy moving forward • The student thinks about next steps with the mentor’s direction • The student verifies information received before moving to the next step by the direction of the mentor.

Table 8 continued

	3. Teamwork	Teamwork: A skill that includes the expertise that involves "interaction between two or more individuals working together to solve problems" effectively (NCREL & Metiri Group, 2003, p. 47).	• The student explains how the mentor was involved in the process by providing information about how the mentor helped the team • Student offers evidence of how the mentor was involved in activities (e.g., ensure collaboration) • The student shows the independence of solving team issues after direction or advice from a mentor • The student uses methods of voting to manage conflict with team members after advice from a mentor • The student listens to reduce misunderstandings after advice from a mentor • The student uses negotiation strategies to solve conflict with team members based on the direction of the mentor.
	4. Communication	Communication: A P21 Learning and Innovation Skill that students demonstrate through expression using various exchanges of information by way of various tools, transmissions, and methods (NCREL & Metiri Group, 2003).	• The student explains how the mentor helped with verbal skills • The student explains how the mentor helped with written skills • Student provides evidence on how the mentor has helped strengthen written skills • Student provides evidence on how the mentor has helped strengthen verbal skills

* Adapted from P21 (2011), Ehsan et al. (2018), and Crismond and Adams (2012).

4.2.1 How Do Mentors Impact Student Participants' Advancement Of…Problem-Solving?

Problem-solving is referred to as creativity in solving problems within the STEM skills 4C's. Problem-solving involves troubleshooting. Students must process information and use their creativity, ideas, and options to find a solution to a problem. There were many ways that mentors taught, promoted, and supported the STEM skill of problem-solving. Support was often in the form of teaching and guidance. The mentors were familiar with the rules of the robotics program. Mentors were able to support students with problem-solving by offering suggestions and explanations and encouraging students to think about solutions that could potentially work, combining the understanding of the program expectations with their own field experience.

The Rural Program

This year was **Evelyn's** second year in robotics. She enjoyed being a part of a robotics program because of her interest in STEM. She also appreciated working with robots in the program but wished there were more girls on her team. She reflected on her first experiences in robotics, and how her mentor helped her build her knowledge to understand key concepts and problem-solving starting with her first encounters with robotics:

> The first year we [team] did this, he [mentor] was with us, and we were just so confused [about what to do], and he worked on the robots like all day before. So, he knew how to explain it to us, and it helped us out. Now, he's just reminding us how to do stuff that he taught us. And if we do find something new that we haven't done before then, he tries to explain it to us better.

The robotics competitions are also fast-paced, where every mistake can cost the team points, so Evelyn needed to go through a process to make sure the robot was working effectively. After taking her mentor's advice during practice, **Evelyn** was more open to taking her mentor's guidance during a similar situation that happened during the competition to create a systematic step-by-step approach to fixing an issue.

> We had to go step by step to show to make this program work. We decided to make a new program right here at the competition. And so, he [mentor] had to help us go step by step to do it and how we should be able to make it. Also, we thought about putting a claw or pusher on to it, and he helped us figure out that if we put another claw on it, he said that it gives another point. And then we showed that and tried it out with him, and it didn't work. So, he was like try to put a pusher on it, and then that worked better than the claw. He told me to listen to what they [team] want; you should try it for one round, and if it doesn't work, then go back to the old way.

In this example, Evelyn's mentor helped her not only recognize her thoughts regarding the problem but helped her develop and understand the decisions that would happen from each of her possible choices by the trial and error method.

Brad, new to robotics, enjoys the math aspect because he could figure out what to do with programming while using math. He is involved in both building and coding and had many different experiences with his mentor. As he describes:

> Well, he [mentor] doesn't really tell you how to do something. He gives you suggestions and doesn't just say you should do this, and you have to that. If it doesn't succeed, then you can do something else. He would first ask what the problem was and what do you think is a way to fix it and then try to help us from there. For one, for a program, he says that we got a really long program, so he's been helping us

> with the program and following steps to be able to get the program right and do that.

In this example above of troubleshooting by creating a step-by-step approach, Brad explained how his mentor would assist him when he could not solve problems:

The mentor in Program 1 also purchased a practice competition field for his home so that he could learn the robot to help teach the students during practice. By understanding the robot on a deeper level, the mentor was able to assist the students in actual diagnosis by guiding the students expertly through options in practice instead of directly telling the students what to do. As one of the students explained:

> He [mentor] has like a couple of robots. He's given us suggestions on other robots that might be better than ours, a little better at something. And he’s trying to help us, not really influence [by others] but figure out a better way to do something. He mostly just goes through all the options and say like, “what do you think is the best way to do it?”

As this excerpt suggests, **Brad** saw the effectiveness of the mentor having access to robotics outside of the program and developing of Brad’s problem-solving skills.

Nelson, who has been a part of robotics for almost three years, was comfortable in all areas of robotics, including programming and building. Here he described how his mentor’s involvement and suggestions empowered him and impacted his activities, including to help him choose robust solutions during the state competition. While **Nelson** admitted that state competition could be stressful, he also described how his mentors helped in navigating his robot in such a tense environment by proposing new strategies:

> He [mentor] gives us ideas and tips of strategies like what piece should go and what happened if we put that piece there. It depends on the robot of what skill the robot can do. So, our robot started on the left side. We'd have to find a strategy to what would work best for the other team and what would work best for us. So, he helped us decide what we should do. He told us “when there's a problem, and you don't want to be too stressed out because that next qualifying match, you're going to be stressed out thinking about the last fall, the last match. And you don't want to do that because then you'll mess up on that match and then so on.”

In this example, the mentor provided ideas and strategies for problem-solving with the robot by showing hands-on experiences in the practice of what functions could work on the robot. Additionally, this example also shows a more personal view of robotics that was beyond the normal scope, i.e., related to the more cognitive and skill aspects of problem-solving, that is, the main focus of this study.

The Suburban Program

This program offers teams for boys and girls. **Madison**'s first year in robotics on the girl's team included doing some things she had never done before, like coding. In one project, in particular, her team was at a standstill on what to do and explained how the mentors helped to develop the next step to find a solution:

> Well, we asked our coaches [mentors] their thoughts on it, and then we [team] talked to everyone, and if someone has a thought on one part and then on the other than we kind of say, "Oh, do you think this is the best answer? Is this one?" So that would be our best answer. They [mentors] really go through all the answers, and then we give ours, we give our thoughts on it, and they [mentors] say, "oh, a lot of you said this. And then some of you said that." So, we really mashed it all together to get to the perfect answer. They help you out and give you a lot of really good advice.

In this example, the mentors assisted Madison's team by evaluating and identifying multiple solutions. In the end, Madison's team created a solution that included input from everyone.

James, also in his first year of robotics on the boy's team, had reservations about his robotic skills and how he could build a robot. However, in this example, he explained how his mentors helped when building the robot with suggestions to his team:

> They [mentors] give us lots of support. So, if we're, struggling or something, they might suggest what we could do. They're not going to tell us what we should do, but they might suggest something. So, they might say, "instead of having these wheels switched in that for other wheels."

In this example, by just offering suggestions, the mentors were able to assist in the actual design of the robot to help James and his team continue building and improving their solution.

In this same robotics program, a theme was defined every year for the competition; this year's theme was Robots in Space. The members of this robotics program were concerned about how robots could help feed astronauts in space. Here, **James** expresses his concerns and how his mentors helped him problem-solve by asking the questions to get to the solution:

> If we're [team] struggling and about what we have already tried, and we tell them [mentor], and they might tell us what works, and then you could tie that into whatever else you're doing. My team was talking about a garden in space because we didn't want people to just be eating the same food over and over again, but we

> need to make sure that the food had enough calories. So, we didn't know how much to grow. And so, we figured out how many people are you going to have on a spaceship? And then how many calories does each fruit or vegetable have?

With the help of the mentor, James was able to identify problems by asking questions to assist in the actual diagnosis of the problem. In this example, learning is occurring beyond the context of robot design, as shown in the STEM research project.

Katie enjoyed her first year of robotics on the girl’s team and usually welcomed the advice of the mentors. As she explained:

> He'll [mentor] give us some advice about what options are and which one sounds best. We'll try it. If it doesn't work, then we always know the second one’s easier. Well, usually they know more about robots than we do, of course. And so usually if we have a question if our robot was not working. And with programming like building as a team, how to measure things. They've helped us with a lot of things.

In this example, **Katie** spoke about the importance of having the mentors help troubleshoot the robot as well as do the programming. She also spoke about the importance of the mentors giving advice when necessary, especially in the high-stress competition season.

The City Program

Angela, a first-year robotics student, with keen interests in science and design, focused on building the robot for her team. Her mentors, who work in STEM professions, want her first to try to understand the problem before providing a solution. Here **Angela** explains the process she learned for solving a robotics problem:

> They [mentor] help us solve a problem. If we [team] were having a problem at the beginning, and she [mentor] helped us with it [robot] by like saying, “well here's what you probably need and look at this and this to see how you could, try to somehow involve that into what you have and make changes.”

While at the competition, the mentor also helped **Angela** troubleshoot the robot, and then after the competition to debrief on what happened and how to fix the robot for the future:

> She [mentor] helped us at first when I went with the A team, so afterwards when we're done, she said, “so when that happened to you, you turn it off, turn it back on. If it's still doing that, you keep doing it until it actually works or either one the cables are wrong, and we need to quickly fix it.”

In this example, the mentor was able to explain to Angela a trial and error process, as well as some opportunities for improvement for future matches at the competition, were.

Ernest, who had previously learned about robotics through a separate robotics club (i.e., a different program), explained how his mentors help him by being there to help recognize and define the problem. Note below that Ernest's mentors allowed him to try to figure out the problem first before they started assisting:

> If we're really stuck, they [mentor] would help us. They would help us, walk us through problem-solving, to help us solve the problem. They would help us get to a certain website to help us, or if they already knew how to solve the problem, they will help us. They would also help us figure it out.

Ernest also described a time where his mentor was impactful at the competition to help solve problems in a competitive environment. Reflecting on his time in robotics, **Ernest** shared an appreciation for how his mentors helped him learn problem-solving skills:

> At the beginning, our robot had problems; all the controls were opposite, so we had to go through the first tournament with the control of being opposite until she [mentor] figured out we should probably get them to configure, which is where we can alter the joysticks. I'll miss how they really helped us get to a lot of problems and helped us with problems with our robotics.

In this example, the mentor assisted in the actual diagnosis of the issue, which was much appreciated by Ernest.

Kallan, also a first-year robotics student with a strong love of math, was a part of the coding and driving aspects of her robotics team. She understood that because her mentors had more experience than she did, they could help with problems that she faced in robotics:

> [Our mentor] help us solve a problem because they kind of have more experience. There was a problem with the bottom of the robot because it wouldn't go over the little blue piece on the floor. So, they [mentor] helped us push it up. They [mentor] took it off and put it up because we didn't know what to do because we needed the motor on the ground, but they helped us figure out why to get it up.

Because of the mentor's help, **Kallan** and her team were able to build the robot and continue to use the robot during practice. By trying different options as advised by her mentors, Kallan was able to see many possibilities before deciding on the one her team would try:

> They [mentor] help us decide because they try different things, and then once you try them on different rounds like practice, they decide which is best because if it doesn't drive or basically goes faster to make it better.

After accepting the mentor's advice during practice, Kallan and her team used the skills of testing options for competition. During the competition, **Kallan** asked her mentors for advice and how to enhance the robot after not scoring the points needed for her team:

> They [mentor] help us determine which answer is best; they might have us drive it and see if it works correctly. Or we might try a bunch of different things to see if it's if anything is better than the other.

In many of these examples, students demonstrated an understanding of how the mentor impacts problem-solving. They also demonstrated an understanding of how the mentor's experiences and expertise helped with creative thinking.

Overall, findings indicated that mentors provide expertise and advice that promotes creative thinking and problem-solving skills among their students. Sahin (2013) recommended that STEM-specific skills be taught by field specialists for effective and meaningful learning to take place. The findings from the study support this by presenting the impact of using mentors that are professionals in different areas of STEM, and the findings add to the literature of Sahin (2013) by presenting specific examples in the areas of mentoring children with robotics.

4.2.2 How Do Mentors Impact Student Participants' Advancement Of…Critical Thinking?

Critical thinking is one of the 4 C's of STEM skills. Critical thinking involves conversations and inferences and often involves reflection on what has worked or failed for similar situations. Students are mindful of information and options to aid in finding a solution. There were many ways that mentors taught, promoted, and supported the STEM skill of critical thinking. Support for critical thinking often came from sharing experiences. Mentors shared their experiences and knowledge about a topic and then encouraged students to talk about how their situation may be similar. Support also came in the form of teaching students how to brainstorm and collaboratively listen and provide suggestions.

The Rural Program

Evelyn expressed how her mentor used methods to get Evelyn to evaluate the next steps with the practice robot, including writing down what happened to reflect at a later time. These methods suggested by the mentor shaped Evelyn's process of thinking through steps to find design solutions for the robot:

> Well, he [mentor] says, “okay, this is what I would do.” Then he explains what he was doing. Then we tried to go over it, we didn’t want to copy down his idea, but he said, “what if you change it up a little bit?” Then, he explains why. After, he says, “go write this down on your drill journal because it can help you out at a later time.”

While explaining the competition theme of war robots, **Evelyn** showed how her mentors were able to explain the history and reason for building such robots to gain further understanding as she was mindful of the information shared and was able to consider her options:

> One time, the theme was World War 2, he [mentor] helped me see why we were doing it. It helped us [team] crack the code, so we didn’t just change the whole code again. He always helps us figure out where to go at a certain time or helps us figure out new strategies to deal with the team.

In this example, a competition theme was also taught as a way to show how robotics could have been used in a previous era.

While explaining how his mentor helps him think about decisions before competitions, **Brad** reflected on how his mentor helped him decide if an idea for changing the robot is essential:

> He [mentor] tries to make sure that we're actually making the right decisions. That if something is not important and it's a day from the competition, you won't do it because he says that we don't really have time. You shouldn't worry about it.

In this example, time management is also mentioned by the mentor as something to consider when evaluating choices.

In addition to deciding if a change to the robot close to the competition is necessary, **Brad** continued to describe how his mentor uses the notebook for further evaluation at the end of practice.

> We [team] have to enter something about what we did that day or strategies or something in the notebook every day. And so, he mostly just wants us to do that.

By using information from the notebook during practice, **Brad** demonstrates the mindfulness of available options written in his notebook.

The Suburban Program

During robotics practices, **Madison** and some of her teammates were in charge of research and development. While researching ideas and approaches on the laptop, her mentor helped her create a strategy by thinking about options:

> Well, he [mentor] worked with us [team] a lot, and he helped us, we had three people on the research team, and he said, "one of you researched this one, one should write it down, one of you like research that." So that was really, really helpful. He also says you might want to check again or add something.

Receiving assistance from her mentor allowed Madison to assess resources for effectiveness and be mindful of her options.

Alison, who joined the robotics team to practice science and program the robot, was a part of the team that built the robot. As she stated:

> They [mentor] tell us to keep testing it because if one thing goes wrong, they'll just tell us to keep testing until it [robot] does it multiple times. They keep having us test it and reflect to make sure that we will do good.

In this example, Alison demonstrated awareness for the reflection of self and others (critical thinking). She also spoke of how her mentor wanted her to continue to test and think to find the solution.

Reflection and inferences are significant components of critical thinking in STEM. Assessment of strategies and options is also a valuable component of STEM learning. **Katie** explained the patterns of thinking and reflection to find the answer during practice and competition:

> If we [team] are thinking something, they tell us to think of something else, or they'll just tell us nicely, "maybe you should think of something else, or maybe you should try to listen to the other team." In competition, he wants us to figure it out ourselves.

The City Program

Alene, who joined robotics to build things and because of her expressed love of math, which she said aided her in logical thinking, explained that by giving the rationale behind an action, she was able to make her robot better:

> [Mentor does this] By telling us reasons why. She is like, information is correct because it tells us different kinds of things that can affect us and what could make it better.

During the competition, **Alene** also spoke about the stress of having disagreements with a teammate and how one of her mentors was able to assist in helping **Alene** think through solutions:

> I think it was the second tournament that we had, and like we [team] disagreed that, I was telling my partner that we should hang first. I told them [partner] to get the

> hubs in, and the other person’s not doing it, and our coach [mentor] said it's more important to get the hub in than hanging. Hanging is cool, but it doesn't give you much points.

As shown in this example, Alene spoke about the importance of her mentor in finding solutions to handle disagreements with her teammates during competition.

By mentors teaching necessary online research aids, **Ernest** was able to learn how to evaluate and discern information and verify resources. Information literacy and making an inference is part of critical thinking, and the mentor who was a media specialist was able to share this lesson for students to build a knowledge base.

> They [mentor] at the beginning of the year, we had a program that helped us with the computers that had like different websites, like .com, .org, and things. We [team] could see if they [websites] were made by a certain company, which ones we could trust, like the school, the company, the websites that were made by the schools. We could definitely trust by the government; we could definitely trust. They taught us for .com if a website has .com in the name that we should probably look at different, multiple sites to see if that's correct. And then .org, we shouldn't trust all the time because it's made by different people.

In addition, **Ernest** was able to evaluate the configuration of the robot after each tournament, which is relevant to critical thinking and the assessment of the effectiveness of strategies. **Ernest** explained that his mentor was able “to check in the configuration to our driving.”

Additionally, **Kallan** discussed how her mentors helped her verify information in robotics and research by checking and reflecting on the information. By having her mentors verify her information, Kallan was more confident in her decision to go forward with the correct information:

> They [mentor] help us to make it important, they might do something or check it, or if we have something that we think is correct or they can make it better, they'll help us do that. They help us decide if we have the correct information by checking what we're doing, like if we're making something on the computer that we're going to print, they make sure that it's correct and that we spell everything correct and we list the correct information.

Regarding the competitions, **Kallan** also expressed how her mentors helped them assess if ideas are sound and accurate so that the team could go further with building:

> They [mentor] help us determine if our idea is good, they know more, and they'll help us determine if it's good for robotics because they know robotics and they know steps that would be good for us. They help to make sure it's correct by, they might check it sometimes, and they have us check and see if we have them correct. Also, they might switch up a part if you don't if we can't get it correctly.

Again, Kallan explains how the mentor will double-check the information to make sure her team is going down the correct path.

Overall, the findings from each of the programs offered evidence to support the impact that mentors had on STEM skills. Critical thinking involves inferences, self-reflection, assessment for effectiveness, and an understanding of available options to solve a problem. Students shared many experiences that were relevant to these components. Many of the mentors taught skills that proved useful in the preparations for competitions. Mindfulness and time management were mentioned as effective for many students. In their study, Sarama et al. (2018) conveyed the importance of mentors of STEM programs, which encourage young students' critical thinking and reasoning abilities. The findings from the study are relevant to the findings of Sarama et al. (2018) concerning quality STEM learning that requires structure and time. The findings offer an extension of the importance of support systems through the provision of feedback from young students concerning the impact of mentors and the advancement of critical thinking.

4.2.3 How Do Mentors Impact Student Participants' Advancement Of…Teamwork?

Teamwork is referred to as collaboration within the 4 C's of STEM. Teamwork involves an exchange that occurs between individuals that work together to solve a problem and create a solution. There were many ways that mentors taught, promoted, and supported the STEM skill of teamwork. The dynamics of each program vary, and some teams had team members that were new to group competitions. Mentors provided teamwork support by offering advice on how to work together, value each opinion, and contribute to the overall efforts of the team. For the skill of teamwork, mentors offered guidance and encouragement to promote a positive and respectful environment.

The Rural Program

By the mentor, listening to each opinion on the team during practices, **Evelyn** saw how to work together with her teammates to solve problems by considering other perspectives:

> Yes. He [mentor], whenever some of the teams get into a fight, he's telling him to calm down and think about what it would be like. And then he takes each of them out in the hall by himself, and he says, "what would it be like if you were arguing with yourself, you're the only person on your team what would you do, or would

> you just go ask someone else for help?" So, he tells them that that's why he's here, is to help each other out, and they bounce back and forth ideas.

During the competition, teamwork was demonstrated through the exchange of information and the efforts made to listen and consider another's ideas. **Evelyn** also explained how the sportsmanship lessons given by her mentor were helpful when competing with another team:

> Yeah, I'm always at the beginning of the competition. He [mentor] goes over to us and says that we need to shake hands with the other team. I'm the nice one, respectful, and listened to each other.

In another competition situation, **Evelyn** talked about how her coach helped solve problems with her and a teammate. In competition, robots are often programmed to use a claw to pick up an object, drop an object, or move an object. As she explained:

> This year me and my team members had a disagreement where we could put a piece on the claw, be able to knock it off, and like I was saying no, because if it was in the middle, then we couldn't be able to pick up the hubs. And I didn't think it would work well. So, he [mentor] said, "Imagine what would it be like if there was a piece in the middle or just on the side." And I thought about it that way.

In this example, the mentor improved the student's teamwork skills by intervening in the design process.

After working for weeks preparing for competition through practices, **Nelson** noticed the independence that was given by his mentors because they trusted his team to work together to make the right decisions during the competition:

> He [mentor] lets us make our own decisions most of the time because we're a team, and we need to talk to our own team members and to see what we should do.

After the competition, **Nelson** additionally reflected on how vital communication is when working with other teams to compete successfully and how this skill will help him in the future:

> Our coach [mentor] taught us how, how to communicate with teams and because that's the biggest part of robotics, you have to talk to the other team members because when you get into high school, it's a bigger field and that you need to prepare yourself for social skills because you're going to be talking to when you're facing another team. So, you're going to need more cooperative skills in social skills to talk to those teams because it's not mostly strategy in high schools.

In this example, Nelson explains how skills learned by his mentor in practice could impact other social and teamwork situations, including future robotics competitions at the high school level.

With his mentor using critical thinking to teach his students about teamwork, **Brad** was able to better understand and articulate decisions with his teammate. By thinking through a solution together with his mentor, Brad was able to work through a problem with his teammate:

> Yeah, he [mentor] has, well, usually if we don't want to do, if I don't want to do something or my teammate doesn't or want to do something, he would mostly try to help us figure out the right thing to do and explain which one might be the best one.

The Suburban Program

On the first day of practice, the mentor explained to **Katie** what being a teammate means and how to solve problems or altercations between teammates by voting:

> On the first day, when we met the whole team, he [mentor] explained to us that what was a good teammate. And so, if somebody wasn't doing something good, they would remind them that they need to be a good teammate. So, we'll explain to them what ideas we have, and they'll tell us like they'll make us vote, and whichever idea gets the most votes. That's the one that goes on because most people agree with one thing, but sometimes we'll just get into a big fight, and then five minutes later, we'll be all like apologizing to each other because we don't like fights.

In this example, the mentor explained what it meant to be a good teammate and how to properly engage with teammates even though team members might not agree.

With support from mentors, **Madison** learned to help her teammates when they are stuck and how to divide into smaller teams to hear more voices:

> They've [mentors] just taught us to work together and get along and say, “if someone's stuck on something, go and help them out.” Some people also had disagreements during the robot [build], so they said, “oh, how about you split up to two teams and work on that?”

By having a smaller team, the group was able to split the amount of work in manageable chunks to reduce disagreements and get the work completed.

In addition to considering all options, **Alison also** learned from the mentors to listen and take in to account other perspectives, as well as to speak up for those who might be quieter:

> They've told us that we have to look at it everybody's point of view and consider all the options. Yeah, we've like, sometimes somebody can get like really caught up in what they were saying, and somebody else has a good idea, and they won't really speak up. And so, he'll [mentor] will be like, “well, why don't we listen to this person's idea?” And that's the way to end up doing it.

In this example, listening to different opinions provided a pathway to work together and solve problems.

Inclusion and sharing responsibilities were **James**’ focus when explaining how the mentor helped his team solve problems. This focus can help students as presentations to judges are required in some competitions. In addition, when there is a disagreement with his team, the mentor’s ability to give **James**’ team choices helps in designing robots and creating presentations:

> If somebody feels left out, they [mentor] usually call the team over, and they give a talk, and they’re like, this person is being left out, and we should give them more support. Or if one person's doing it all or if there's one person who's not working, then he might call them over and say, you need to start working because what you do affects the team.

James went on to explain that when disagreeing with his teammate, the mentor’s lessons on cooperation and negotiation are highlighted. In addition, the mentors use deep-breath techniques to diffuse tense situations that the team might have with other teammates. As he explained:

> If we're arguing, they [mentors] might tell us to calm down and try and compromise with it or try one idea and then try the other and see which one looks better. Sometimes I'll be kind of skeptical on what we should do for the poster, what the team should say. And so sometimes the coach comes over and says it's just like just a majority rule of what we should do. Or you can try and incorporate what everybody else wants.

In this example, mentors highlight specific cooperation strategies that include communication, trust-building, and conflict management. In addition, negotiation skills were also learned that included listening to other students in the group, including to reduce misunderstandings.

The City Program

By learning how to listen to others with a difference of opinion, the mentor helped **Angela** and her team listen to the ideas of everyone in the team to come up with a solution collectively:

> Because it's nice to have her [mentor] be there and helping us get back on track. If we have a disagreement, she sees like, what both ideas are, check them out, and then we see which one kind of works best. Cause last week we were meeting up we were trying out for the big boulders, and she didn't want to make humongous changes in our little time that we had, and they were wanting to like make the bulldozer big, and they had to take apart the bulldozer that we already had and make room for that and so. We still had to listen. Yeah, she'd say, you know, listen to

> your partners even though you might not agree with them and stuff. You have to kind of like do that in class.

After the competition, **Angela** strengthened this by saying, “Just work with your team, and you'll get a lot done.”

To explain how her mentor pushed her to think about a situation critically, **Alene** expressed how her teammates worked together to modify the robot after a disagreement. By hearing the opinions of the team, the mentor was able to create a process to help team members listen to each other, to understand which idea should be considered:

> She [mentor] tells us to be nice to each other and tell each other ideas. Like two other people were talking on two different things, and then the coach said, “what's wrong” and then the people [team] told them what they were thinking and then she [mentor] told them that one idea could be better and the other one could be better, and the other one could be better, but we have to think about the effects that will happen to the robot. So then, if we wouldn't listen, we won’t be able to learn, and if we didn't listen to other people's ideas, we wouldn't have a good robot, we would've just be messing around and just fighting.

In this example, the mentor was involved in team dynamics by offering to help them think through multiple scenarios to resolve team conflict.

Also, in the next example, **Ernest** expressed how the mentor’s advice to compromise and listen to others was relevant when solving disagreements with teammates. By working through the needs of others, the mentor was able to aid the team to better compromise:

> One time, two of my teammates got in an argument of how the base was made. One thought it was okay, and the other thought we should probably make it smaller because it was big. And then she [mentor] said, “we'll leave it how it is now and then if it does well in the tournament, and then we'll change it,” and that seemed to help both the sides. They would usually like pull them to the side and say like, don't forget like they would remind you to not forget to try to listen to the other person's ideas and see if you can try to understand the ideas or the other person. It kind of helps like if the adults see that an argument is about to occur, they would help, they would try to end it before it happens, I really liked that about them because it helps things go better.

After the competition, **Ernest** shared that his mentor helps him see “that you should always be open to other people's ideas.” Many of the students observed demonstrated a good understanding of teamwork. The competitions are completed in groups, so teamwork is essential to do well.

Overall, the findings from each of the three programs offered evidence to support the impact that mentors have on establishing and maintaining teamwork. Some of the common components involved in the team composition and participation in a robotics STEM program included preparation, communication, listening to differing opinions, decision making, compromising, and reflection. These components proved useful to many teams in having a mentor help address. These results are complementary to the findings of Wallace (2014) concerning the importance of having access to a mentor when learning through social activities. The findings indicate the meaningful impact that mentors have on students that are elementary age students, specifically around teamwork.

4.2.4 How Do Mentors Impact Student Participants' Advancement Of…Communication?

Communication is another critical component of the 4 C's of STEM education. Due to the nature of the program and the competitions, communication is essential for group success. Communication involves the exchange of information verbally or through writing. There were many ways that mentors taught, promoted, and supported the STEM skill of communication. Effective communication takes practice, and mentors supported this skill through demonstrations, examples, and providing time to practice. Feedback and guidance offered to students by the mentors helped the team members verbalize their thoughts and gain practice in presenting and communicating more effectively.

The Rural Program

Preparing for discussions with judges and other interactions during the competitions can be stressful. **Evelyn** explains how her mentor creates a positive practice environment for competition by giving the students mock interviews:

> Yeah, he [mentor] sometimes takes us out in the hallway and acts like he's one of the judges coming up and talking to us about the robot and stuff.

Different from the above example, in the next example, Brad explains the importance of the mentor's lessons in communication with teams.

> Our coach taught us how, how to communicate with teams and because that's the biggest part of robotics, you have to talk to the other team because when you get

> into high school, it's a bigger field and that you need to prepare yourself for social skills.

The Suburban Program

At the end of practices, the Suburban Program usually ended with a recap of the events or speech practice in both the girl and boy teams. **Madison** spoke about how her mentors assisted her in preparing for competition through speaking exercises:

> Well, we practice a lot, and they [mentor] told us they timed us, and they said, "maybe you need to add a couple more parts." Like we were working on speeches for presentation; I was really stumped because I forgot what part I had to do; they helped me talk through it, "what are your thought on this?" And then mashed it all together. We really made it an awesome speech.

James, through the process of practicing for presentations, also found that the mentors helped him feel more prepared to talk to judges.

> They [mentor] helped us practice. So, they'll sit there, and then our group will come up and present our poster like we would do the judges in. That prepares us.

Logan, also a first-year robotics student, like **James and Madison**, attended mock presentations led by the mentors to help him feel more confident and equipped to speak in front of judges than before practice presentations:

> They help us practice by taking us into hallways like we don't have anyone watching, but we practice what we are saying.

The City Program

After having **Angela's** mentors explain the purpose of presentations, she felt more confident in presenting and felt that her team could practice on their own without mentors:

> Yes, because they [mentor] helped just like, figure out what we [team] need in them and then what we didn't need them.

With the help of critical thinking skills taught by his mentors, **Ernest** additionally expressed how his mentors assisted him and his teammates reflect on their content and feelings before presenting:

> They [mentor] usually let us think about what we want to say and like how we feel about the situation.

In these examples, the mentors were able to help the students develop their verbal communication skills by helping them practice speaking to judges at competitions, and by allowing time and space for writing in journals during practice.

The findings provided evidence that mentors provide an impact on the advancement of communication skills. Based on the feedback from participants, mentors were instrumental in helping students prepare for competition. Preparation may have included components such as providing a positive learning environment, mock presentations, and other supportive conversations to prepare the students for potential situations they may face concerning communication with judges.

4.3 Further Findings

Although the significant themes of the study included the four main STEM skills of problem-solving, critical thinking, teamwork, and communication, other sub-themes were noted throughout data analysis. Some of the sub-themes present in this study are troubleshooting, trial and error, negotiation, and public speaking. Each of these sub-themes is relevant to the informal mentor support of a STEM skill.

Troubleshooting is a sub-theme of the problem-solving STEM skill. Ehsan et al. (2018) noted that troubleshooting is often used to help students diagnose a situation in order to solve the problem. Many students from this study shared experiences demonstrating how the practice of troubleshooting learned from their mentors helped them break a problem down to find a solution.

Trial and error is a sub-theme of the critical thinking STEM skill. Ernst and Monroe (2004) noted that students need a set of skills that can help them evaluate and make decisions, such as reflection or trial and error. There were several observations made in this study to support the mentors informally teaching the skill of reflection using trial and error.

Negotiation is a sub-theme of teamwork or collaboration of STEM skills. Negotiation involves the exchange between individuals working effectively to carry out a task (Menekse et al., 2015). Through the encouragement and support of the mentors, students were able to negotiate possible solutions to problems faced.

Public speaking is a sub-theme of the communication STEM skill. Many mentors offered support to students that were not experienced in speaking in front of a panel of judges or to an audience. This support in public speaking helped encourage students in their abilities to present their ideas verbally. Jang (2016) noted how STEM programs help promote communication skills among students, and there was evidence of this support as expressed during student interviews.

4.4 Summary

The main question that guided this study was: how do mentors impact student participants' advancement of specific engineering skills, including problem-solving, critical thinking, teamwork, and communication? The three programs: rural, suburban, and city, each with different demographics, resources, and mentor experiences, had an of a variation of resources and materials to integrate an after-school robotics program as outlined below.

In the Rural Program, the students were able to describe actual situations that the mentor impacted related to problem-solving, teamwork, critical thinking, and communication during competition or practices. For example, in problem-solving, students used examples of how the mentor recognized the problem the students were facing. When the students first started practice, they were confused and did not know how to use the robot. The mentor immediately recognized this as a concern and began explaining the robot in smaller chunks so that by the time competition came; students were more confident about the robot and skills they learned due to the time the mentors spent with them at explaining at practices. In addition, by teaching students how to include all ideas in the decision-making process, students were able to learn vital teamwork and communication skills like imagining something from someone else's perspective. By doing this, students were able to think of others to solve a problem during robotics.

Despite the Suburban Program being split into two teams on separate days (boys on one day, girls on the other), the mentors made a conscious effort to teach the same lessons each day. Each team had its own way to discuss problems but always ended on a technique taught by the mentors for conflict resolution of team member inclusion. For example, to help with conflict, the mentors taught both groups the resolution technique of majority rule or voting to pick the preferred solution. In addition, critical thinking skills of inquiry and reflection stood out to students as a top theme that the mentors taught the students as they felt comfortable considering many possibilities before landing on an answer or approach. Lastly, mentors successfully explained to their students how to identify and follow the steps needed to find solutions and to build the robot. In addition, students explained the importance of having the mentors assist in troubleshooting as well as programming.

After this experience, students were also more comfortable with refining explanations by themselves after the mentors explained how to complete certain tasks.

In the City Program, all students interviewed enjoyed the perceived independence allowed by the mentors even though all students gave an example of how the mentors helped them in all STEM skills areas researched. For example, by showing the students how to correctly research articles on the Internet, students felt permitted to be able to complete fundamental research by knowing the difference between government, company, and organization sites. In addition, collaboration skills among the groups were seen throughout problem-solving and critical thinking as students gave examples of how mentors helped the students work through conflict resolution to troubleshoot the robot while reflecting on the intentions of the group. Mentors supported students as they performed troubleshooting tasks through all steps of the robotics program, including by helping them recognize and define problems at each stage. In practice, the mentor helped the students understand the problem of how to build a robot before providing a solution, leading to further understanding of problem-solving. In competition, after the students asked the mentors for advice, the mentors were able to help students troubleshoot the robot and then after the competition debrief on what happened and reflect on how to fix the robot for the future.

5. DISCUSSION

Growing and diversifying student enrollment in STEM fields is imperative for the nation to stay in front of innovation (Holmlund et al., 2018; Kuenzi, 2008; Tanenbaum, 2016). To support this objective, in recent years, there has been strong language regarding the need to expand and improve STEM education for pre-college students. However, current analytics and metrics show slow to no growth in pre-college career interest in STEM and little guidance on best practices for integrating STEM in early childhood education (Chubin et al., 2005; Leggon, 2018; McNeely & Fealing, 2018; Wolfe & Flewitt, 2010). Even though informal programs can be used as an avenue to increase awareness and involvement in pre-college STEM programs, little research has been completed regarding the success of the many informal (i.e., out of school time) programs to encourage interest in STEM-related careers (Smith, 2015).

Against this backdrop, the formal research question that guided this study was:

> How do mentors impact student participants' advancement of specific engineering skills, including problem-solving, critical thinking, teamwork, and communication?

An essential part of the study was to interview and observe elementary students involved in afterschool robotics programs, and to hear first-hand stories and situations in which mentors were involved in their learning. Essential to the study was the observation of interactions with mentors and students in a robotics program to see STEM skills in action.

The larger purpose of this study was to examine the involvement of mentors to help teach elementary students STEM skills that may impact their lives. By investigating mentors' and elementary students' connection in informal STEM programs, contributors to STEM education can be empowered to generate corrective action to enhance STEM skills progression and remain on their mission to generate knowledgeable students. In other words, the skills that mentors teach through the STEM program encourage juvenile self-reliance and problem-solving.

Three programs were investigated using a collective case study approach. Each program had different demographics and contextual features, including a variety of resources and materials needed to implement an after-school robotics program. Data were collected through interviews with students and mentors, observations of robotics practices and competitions, and review of the teams' engineering journals. This chapter discusses key findings and conclusions, including recommendations for both programmatic improvements and further studies.

In summary, the researcher observed how each program was impactful because of the tailored approach mentors took toward working with the students. In all programs, the central theme in problem-solving was helping students process appropriate explanations. Even though the results were not cross-analyzed by program, all programs had mentors who sought to increase knowledge and skills among the students even though each program had partially distinct backgrounds, contexts, and reasons for forming.

5.1 Key Insights Concerning Mentors and STEM Skills

Each robotics program had very different demographics and mentoring styles, but all presented the integration of STEM skills and robotics in an afterschool program. With each program, clear evidence was found concerning the impact of having an experienced mentor working with the students. The presence of a mentor can help students become more interactive, engaged, and enthusiastic about STEM. Mentors have helped promote and enhance the STEM skills of students involved in each of the programs. More specific insights related to the four STEM skills (problem-solving, critical thinking, teamwork, and communication) are presented below.

5.1.1 Problem-Solving

Across all three programs, the STEM skill of problem-solving (see Figure 3) was an area where there was the most evidence of mentors impacting students. In particular, mentors helped students process appropriate explanations for why a situation was happening and how to address or resolve it (see Table 3). The mentors' impact on problem-solving skills was likely observed most often because of the mentors' knowledge to help the student understand the problem by defining the end goal, and the nature of the STEM program design tasks that tend to concentrate on problem-solving. The other STEM skills researched were also observed in all three programs, but less frequently.

5.1.2 Critical Thinking

Critical thinking is another important skill that mentors can help encourage through the STEM program. A student from the rural program expressed learning critical thinking skills through the help of the mentor by encouraging the evaluation of choices needed for the robot, organized thinking and processes, the reflection of actions taken, and consideration of information shared among the team. In the suburban program, students learned about critical thinking through skills learned through the mentor's research and development efforts and creating strategies to solve problems. In addition, after each robotics meeting, the students were advised by the mentor to reflect on the activities from practice critically. The city program had similar experiences with learning critical thinking skills through the actions of the mentors. In this program, students learned critical thinking through logical thinking, and the mentor provided rationales from various robotic problems, assisted the students in seeking solutions, and evaluating and assessing the effectiveness of various strategies. The skills that mentors help instill and nurture can translate into life skills that are useful outside of the STEM program curriculum.

5.1.3 Teamwork

Many programs encourage teamwork and enthusiasm through the use of program themes and team names. The students usually create the theme with guidance from the mentors. One student from the rural program reported learning how to work together with her teammates to solve problems using advice from her mentors related to considering other perspectives. A student from the suburban program explained that being a teammate meant learning how to solve problems or face altercations with other members of the team based on cooperation advice from her mentors. In the city program, a student claimed that their mentor helped her team listen to the ideas of everyone on the team to come up with a solution, collectively demonstrating teamwork.

5.1.4 Communication

The mentors' impact on communication skills was not as directly seen but can be viewed in all other skills. One possible reason why communication was less frequently observed might be because it is integrated into all of the other STEM skills studied (problem-solving, critical thinking, and teamwork) and can be seen in how students communicate with other team members, sometimes while problem-solving or using critical thinking. In addition, the communication interview questions that were asked by the researcher focused more on communication that takes place at a competition with judges interviewing students and evaluating their presentation, rather than other types of communication such as interactions within the team. However, students described how the mentors helped them present in competition, and also gave multiple examples of how the mentors helped them communicate with their teammates to solve problems.

5.1.5 Mentor Impact Outside of Robotics

Explanation of STEM skills was used to link students to activities outside the classroom. For example. in the Suburban Program, the mentors saw the importance of making the connection between the robotics program and the outside world. Because the theme was robotics in space, mentors involved outside specialists from the community, like a nutritionist and a gardener, to explain the importance of nutrition in our daily lives. Because of this, students were able to problem solve what nourishment might be needed for astronauts in space. For example, one student, **James,** explained how, after gaining the expertise from the nutritionist and gardener, he was able to problem-solve his concerns with his mentor. He used the knowledge gained from the visiting experts to have a meaningful conversation (not robotics-related) with his mentor on the importance of nutrition and sustainability.

5.2 Recommendations and Discussion

While the discoveries from this study cannot be generalized, the findings can aid as illustrations for developing more impactful elementary school robotics programs. The findings are also congruous with the literature available on mentor involvement in helping students gain STEM skills. More specifically, each program showed examples of mentor impacts on students related to the STEM skills of problem-solving, critical thinking, teamwork, and communication. Each program had mentors from different backgrounds in STEM, but all had STEM experience to give back to the students in their program.

Robotics encourages the development of problem-solving, critical thinking, and collaboration through a hands-on curriculum. The intention of robotics programs, like the ones observed, aims to provide a test-problem framework in a team setting that promotes students to explore technology and innovation. All observed programs included 21st-century skills, examples of problem-solving, critical thinking, teamwork, and communication. Not only did the robotics programs offer students 21st-century skills, the programs impacted students in a variety of meaningful ways, including by providing participating students with a) increased awareness of robotics, b) access to experts, c) scaffolding, and strengthening of STEM skills.

In the sections that follow, four significant recommendations are presented for other programs to consider concerning the role and impact of mentors. These are inspired by observations and evidence from all three programs and could assist in the future for designing more effective informal STEM programs.

5.2.1 The Learning Of STEM Skills Should Be Based On An Intentional Education Approach

In each of the three programs, all the STEM skills for this research project were observed, which was aligned with the overall robotics program objectives of creating tools for future problem solvers. In multiple studies reviewed, robotics was similarly found to increase knowledge of STEM skills, including problem-solving, critical thinking, teamwork, and communications (Carberry & Hynes, 2007; Eguchi, 2014; Kazakoff & Bers, 2012; Marulcu, 2010; Oppliger, 2002).

When used effectively, mentors can help students understand the link between STEM careers and STEM-related projects (Caligiuri, Mencin, & Jiang, 2013; Karcher et al., 2006; Seiler, 2001; Wallace, 2014). According to Hirsch et al. (2007), students are not selecting STEM careers because of a lack of connection to interest. Therefore, deliberate action is needed.

To gain the interest of students, initiatives such as the STEM robotics programming can be used. Additionally, STEM skills can be better integrated into informal STEM programs by more deliberately introducing and explaining the steps of the engineering design process. The National Research Council (2011) emphasized that authentic and intentional STEM integration in pre-college learning helps strengthen STEM-based knowledge, as well as create a long-term basis of understanding. The Natural Research Council (2011) proposed a curriculum in which students respond to learning activities through engineering design. These STEM lessons offer further learning creative and critical thinking, enquiring, and meta-cognitive reflection, as well as engineering design skills.

Using a diagram to explain the engineering design process would also be a recommended approach. The representation of the engineering design process is an example of a set of enduring understandings, or " generalizations that are central to a discipline [engineering] and transferrable to new situations [and a] lasting view beyond the classroom" (Hansen, 2012, p. 147). In the introduction of the VEX robotics curriculum, students learn that engineers use a design process to help with problem-solving. The steps in the design process, at their basic form, involve thinking, doing, and testing. The skills learned in the STEM program combined with the engineering process steps can help build a foundation of understanding that can be applied to many situations outside of the program. The student's engagement in these notions will be heightened because they will participate in defining various tasks.

5.2.2 The Use Of Mentors In Informal STEM Programs Should Give Space For Strengthening Of Skills

As seen in many examples of mentor impact with students in this study, mentor involvement can be used to help students take their learning and development to the next level by promoting work in the zone of proximal development. Per Vygotsky (1978), "the zone of proximal development defines those functions that have yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state" (p. 86). Not only can mentors help reinforce STEM skills and scaffold learning for students, but also in the development can assist students generate better designs and solutions.

In this study, mentors explained new robotic elements based on already learned scientific inquiry and math concepts through social interactions. This building concept process can be seen as scaffolding (Brophy et al., 2008), and collaboration is vital for this transmission of information. According to Vygotsky's, a child can comprehend advanced ideas where their skill levels are pushed. The zone of proximal development highlights readiness and knowledge by collaboration (Mooney, 2013). For instance, mentors were observed offering advice and options for students to consider when they faced a roadblock. Students described instances where mentors helped them think through ideas and options that could solve a problem. Children can achieve more through scaffolding than what they can do alone (Vygotsky, 1978).

Problem-solving, critical thinking, teamwork, and communication can be learned through scaffolding. Problem-solving adds to the foundation of STEM knowledge by teaching troubleshooting and diagnostic skills. Students that use critical thinking can build a foundation of knowledge through reflection, conversation, evaluation, and formation of opinions based on an assessment of the effectiveness of various solutions. Teamwork involves experience with acquired skills (e.g., STEM skills, robotics experience, coding experience) and is successful when groups work together to reach a common goal. Communication adds to the STEM foundation through the skills of reflection, listening, expression, and the exchange of information and ideas.

If a student is close to gaining an understanding of a problem, a mentor can help that student gain the knowledge needed to understand it more fully (Delaney et al., 2017). A mentor conveys practical knowledge and can assist in bringing theoretical understanding to life. Mentors can also share interdisciplinary knowledge to solve a problem. For instance, students from the study shared instances of mentors sharing prior experiences, knowledge, and mistakes that aided the groups in their decision making. Vygotsky’s zone of proximal development is an essential aspect of mentoring as mentors can offer attainable goals to inspire a student (Larson, 2006). By a collective effort with the student, mentors can cultivate students’ deeper understanding of concepts and aid in the extension of knowledge (Rhodes & Lowe, 2008).

5.2.3 Explicit Mentor Training Should Be Offered

Although many mentors are required to go through a background check and minimal district training on working with students, this procedure is not specific to the robotics program and team competitions. In this study, formal professional training was not provided for the observed mentors. Within the context of this study, the main mentors that worked with the teams often informally trained other mentors on the competition components and guidelines. However, there were no designated resources and materials that the mentors in this study had access to. In light of these results, one recommendation for programs is to offer formal mentor training, including specifically to help mentors with teaching and supporting the STEM skills that students need to be successful in competition and life.

5.2.4 Recommendations for Action

Based on the findings from this study of positive mentor impact, mentor training could be used to assist with more programs, which can also have a positive impact on a larger student population; this may be especially true in locations that have very few mentors and/or experienced mentors. However, regardless of the experience and enthusiasm of each mentor, there is a desire for development among STEM mentors of pre-college students to recognize how to integrate their STEM skills in an effective age-appropriate manner. The mentors in all three programs observed had different backgrounds in STEM and different levels of experience working with younger students. In addition, mentors could also benefit from training to help clarify expectations associated with the robotics program.

To achieve these types of outcomes, mentors could participate in a professional online workshop given by organizations like TechPoint or by the robotic companies themselves. The design and the development of such a workshop could train STEM mentors on working with pre-college students, preparing and using subject-specific materials, and enhancing awareness of multicultural dimensions and issues of diversity, equity, and inclusivity. The ultimate goal of the mentor development training would be to increase the presence and availability of mentors to further their impact in different communities. By the end of this course, mentors could:

- Be familiar with the Partnership for 21st Century Skills, including problem-solving, critical thinking, collaboration through teamwork, and communication. Many media specialists and technology specialists are familiar with these skills; however, mentors could benefit from understanding each skill and understanding how these skills are significant to the success of a STEM experience.
- Recognize the opportunity and limits of their role as a mentor. Many mentors go through specialized training in order to work with children; however, each school district may have specific policies in place that mentors must follow when working with students on school property. Understanding these policies and procedures ahead of time will help a program run smoothly.
- Develop the skills and attitudes needed to perform well in pre-college environments. For mentors that have little experience working with young students, training with educators can be beneficial to help mentors understand what to expect as a knowledge base and behaviors to expect for different age groups. Information on how to work with these factors in order to deliver meaningful instruction is important.
- Receive an overview of theories and frameworks related to youth development. This overview can help create an understanding of how a young student learns. This

information can help mentors understand the thinking processes that are common among students.

- Obtain information about program requirements. For the program to be successful, mentors should be informed on the expectations of the program and requirements for participating in competitions.
- Have their questions answered concerning mentor involvement. Mentor training could provide mentors a comfortable environment to express concerns and ask clarifying questions about working with students.
- Explore frameworks and beliefs about diversified learning styles. Mentors could benefit from training that explores the different learning styles that are common with students. This knowledge can help mentors with diversified learning.
- Learn how inclusion can assist in shaping a vital and all-encompassing atmosphere. Teamwork is one of the four skills central to STEM, and inclusion is an important piece of teamwork. Mentors can learn tips from training on how to engage all students and promote inclusion.

Because of the repetitive nature of such training, comments from the freshman class of STEM mentors could be used to advance mentor development resources. Samples of student work could also be shown to mentors as further evidence to work with and learn from in the future. Feedback could additionally be given to the research team to redesign modules if needed.

STEM mentor involvement in informal programs should inspire problem-solving, critical thinking, and positive team interaction by allowing students to create and design solutions in a welcoming environment. Students in all three programs were involved and enthusiastic to absorb new things. This sentiment should be the goal in all STEM programs with mentor involvement.

5.3 Recommendations for Further Study

The purpose of this study was to explore the future for mentor involvement in informal STEM programs as motivations to answer the following question: How do mentors impact student participants' advancement of specific engineering skills, including problem-solving, critical thinking, teamwork, and communication? Chapters 4 and 5 presented findings from three separate programs related to mentor impacts on STEM skills. These results could be shared with other STEM mentors or organizations so they can see examples of their impacts.

The findings from this study are also part of a larger body of research starting to surface on the impact of mentors in pre-college informal education programs; more is desirable. Some specific recommendations for further examination include:

a. Examination of the metric-driven impact of programs and on students. By further determining metrics of "success" for impactful STEM programs, the chance of closing the STEM skill gap could be increased despite the absence of explicit curricular connections. Some metrics might entail STEM involvement at higher levels, including high school robotics programs or a career in STEM.
b. Creation of an assessment tool for program evaluation that can convert results to meaningful measures and language understood by all community stakeholders. An assessment of each skill could be conducted to identify the effectiveness as it relates to a specific STEM program. For example, how effective are teamwork skills in a Lego Robotics STEM program? Program evaluations could help strengthen the programs already in place by highlighting areas of strength and weakness.
c. Longitudinal study about the impact of students involved in informal mentor-led STEM programs as they develop and arrive in the job market would give awareness on best practices for mentor involvement. This type of study would differ from an examination of the metric-driven impact in that data would be gathered over multiple years.
d. Investigation of the mentor perspectives and their perceived impact of students. By understanding the mentor's experience, further details could be understood about the robotic program experience as a whole.
e. The success of mentor training in informal STEM programs. Future research could examine programs that promote mentoring to provide more assistance with STEM programs. Types of practical training for mentors would be beneficial to educators seeking to grow their STEM programming.

Because academic publications are typically read more often by researchers rather than educators or other practitioners, mentors who are involved in informal programs may not be aware or knowledgeable of current viewpoints that could assist in the development of impactful mentor programs. Direct benefits of this research could be an opportunity to connect the domain of education and community stakeholders like mentors, by sharing a systematic collection of research-based insights with critical stakeholder groups.

5.4 Closing Comments

In spite of generous funding, the current data shows slow-moving demographical changes in STEM (science, technology, engineering, and math) fields, and little to no slowing in the decline of STEM-associated career interests in underserved communities (Leeker, Maxey, Cardella & Hynes, 2019). Gaps between STEM education and workplace skills have been identified in industry and academia alike (Jang, 2016). However, little is typically taught to elementary school students to lay the groundwork for STEM skills (Kazakoff & Bers, 2012).

STEM education, which usually emphasizes science and mathematics, also includes technology and engineering to aid students to "develop different strategies in order to solve interdisciplinary problems and gain skills and knowledge in order to solve interdisciplinary problems and gain skills and knowledge in order to sustain scientific leadership and economic growth" (Lacey & Wright, 2009; Sahin et al., 2014, p. 309). Concentrating on engineering in STEM in the early years of childhood development is an excellent place to start engineering education (Bagiati & Evangelou, 2009).

Problem-solving, critical thinking, teamwork, and all methods of communication (verbal and written) are commonly described as absent from recent STEM graduates (Radermacher & Walia, 2013; Tang, Lee, & Koh, 2001). The Partnership for 21st Century Skills (P21) promotes these workplace skills for all students. The P21 shaped a system of fundamental skills highlighting the "3Rs and 4Cs" (P21, 2009). Reading, writing, and arithmetic (3Rs) aid as the foundation for learning. The P21 emphasizes the 3Rs and 4Cs are vital for the workplace today. Because the 4Cs launch the knowledge a step further to contain the skills of problem-solving, critical thinking, teamwork, and communication, they were the focus of STEM skills in this study.

In observing the mentoring impact of STEM skills on robotics students, I found the students to be interactive, engaged, and enthusiastic about working with their mentors. This did not surprise me because the students were comfortable with their mentors, as the mentors were not new to the programs or the students. Each mentor provided the students with the freedom to make decisions while giving clear boundaries, which provided a safe place for the students to explore and learn robotics on a deeper level and develop the types of skills discussed throughout the study.

The study included three Indiana robotic programs and two programs where the administrator of TechPoint reported the use of an outside mentor in the program. I anticipated seeing mentors interacting with students, but I was invigorated by how involved and hands-on the mentors in each program were. In all three programs, the students actively engaged with the mentors. However, this is not the standard because there is a scarcity in the number of informal STEM programs as well as a lack of outside mentor involvement in these informal STEM programs (Tsui, 2007). Thus, mentors who are using an active learning environment for students that promotes engagement and growth should be commended because research has shown that when students are involved and not merely interacting with materials, but creating and using STEM skills, these students have superior learning experiences (Kazakoff & Bers, 2012; Resnick, 2007).

Researchers (Holmlund et al., 2018; Kuenzi, 2008; Tanenbaum, 2016) have reported a national appeal for growing STEM programs to meet the economic demands of STEM-related fields. As STEM-related fields of employment grow, our nation becomes more influential in global competitiveness. Many industry leaders have sponsored and invested in STEM programming to promote awareness and engagement in the fields of science, technology, engineering, and math (Kuenzi, 2008). For this study, mentors' involvement in teaching and promoting STEM skills were evaluated, and findings indicated that mentors do have an impact on student engagement and learning. Mentors that work with students are one key component to growing interest in STEM-related fields of employment. Mentors can help students discover a passion and enthusiasm for STEM.

APPENDIX A. RESEARCH SCHEDULE AND FRAMEWORK

Table A.1. The presentation for interviews with each student

Order	Purpose	Time Allocated
Introduction	To form a relationship, permit the student to become relaxed	5 minutes
Purpose	To explain why the researcher is doing the study	5 minutes
Demographics	To gather background information	5 minutes
Discussion: Problem-Solving	To gather input from the student	7 minutes
Discussion: Critical Thinking	To gather input from the student	7 minutes
Discussion: Teamwork	To gather input from the student	7 minutes
Discussion: Communications	To gather input from the student	7 minutes
Discussion: Mentor Impact	To gather input from the student	7 minutes
Final Thoughts and Closing	End the conversation, gather closing opinions, Show gratitude to the student for their time	10 minutes

Table A.2. Data collection protocol and agenda

Entry	Accomplishment	Timetable
1	Communication, coordination with each mentor (emails, calls)	Week 1-2
2	Sent forms of permission to mentors	Weeks 3-4
3	Receive of forms of permission	Week 5
4	Observations and interviews pre-competition	Weeks 6-8
5	Coordinate with mentors for state observations and interviews	Weeks 7-8
6	Observations and interviews during competition	Weeks 9-11
7	Coordinate with mentors for post-competition observations and interviews	Weeks 10-11
8	Observations and interviews post-competition	Weeks 12-14
9	Data Cleaning	Weeks 15-17
10	Analyze data	Weeks 18-22
11	Data interpretation	Weeks 23-27

Table A.3. Observation codebook of mentor impact on students of critical STEM skills

	Skill Criteria	Code	Actions
Understanding the mentoring impact on Students	1. Problem-Solving (Troubleshooting)	1. Troubleshooting: Although there are many styles and types of problem-solving techniques, for this study, the style of problem-solving reflects the teachings that are commonly seen in STEM education. More specifically, problem-solving is the ability and skill to unravel different situations that are unfamiliar and to make decisions about the best sequence of action through creativity, collaboration, or resourcefulness (P21, 2009).	• The student describes how the mentor assisted in the actual diagnosis • Student offers evidence in how mentor was involved in proposing new ways • The student uses trial and error at the request of the mentor to assist • The student uses a systematic design approach at the assistance of the mentor • The student describes key concepts that the mentor explained to address knowledge gaps • The student describes how the mentor poses multiple options

	2. Critical Thinking (Information Literacy)	2. A P21 Learning and Innovation Skill that involves "purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation…upon which judgement is based" (Facione, 1990, p. 3).	• The student indicates an awareness of mentor involvement in thinking moreover, the reflection process • Student provides evidence of how mentor involvement helped make decisions, evaluate, and/or problem-solve • The student uses reason and/or reflection skills to create a strategy moving forward • The student thinks about next steps with the mentor's direction • The student verifies information received before moving to the next step by the direction of the mentor.
	3. Teamwork	3. Teamwork: A skill that includes the expertise that involves "interaction between two or more individuals working together to solve problems" effectively (NCREL & Metiri Group, 2003, p. 47).	• The mentor is involved in the process by providing student information and ways to assist in team development • The mentor offers direction and advice, and the student takes charge of the situation (independence) • The mentor suggests voting as a way to solve conflict with student teams • The student-mentor suggests active listening to reduce team misunderstandings • The mentor teaches negotiation skills to help resolve conflict • The student uses negotiation strategies to solve conflict with team members based on the direction of the mentor.
	4. Communication	4. Communication: A P21 Learning and Innovation Skill that students demonstrate through expression using various exchanges of information by way of various tools, transmissions, and methods (NCREL & Metiri Group, 2003).	• The mentor helps students develop verbal skills • The mentor helps students develop written skills

APPENDIX B. INTERVIEW QUESTIONS

Student Semi-Structured Interview Protocol (Pre-Competition) – 30-minutes

Greeting: Hello, [insert name]. My name is Jessica, and I am here to talk to you about robotics. I want to begin by thanking you for participating in this interview today. Throughout this interview, I will be asking you questions about your journey in robotics. At the end of the interview, I will leave time to discuss the next steps in this study. If, at any point, you have questions, please don't hesitate to ask. Before we begin, do you have any questions?

To begin this interview, this will be conversational (e.g., how are you?). Before we start, I want to get to know more about you.

Questions

Demographics

1. What do you like to do at school?
2. What other clubs are you a part of?
3. How many years have you been involved in Robotics?
4. What is your primary reason for getting involved?
5. How interested are you in science, technology, engineering, math?

Problem-Solving

Troubleshooting: Although there are many styles and types of problem-solving techniques, for this study, the style of problem-solving reflects the teachings that are commonly seen in STEM education. More specifically, problem-solving is the ability and skill to unravel different situations that are unfamiliar and to make decisions about the best sequence of action through creativity, collaboration, or resourcefulness (P21, 2009).

6. How do you solve problems in robotics? How do you prepare for problems that you don't expect?
7. Walk me through a situation where you had to follow steps in robotics to get something done?
8. When facing a problem, how do you decide which answer is best?
9. How does your coach help you solve problems in robotics?
10. Tell me about a time your coach helped you follow steps to get things done?
11. When facing a problem, how does your coach help you decide which answer is best?

Critical Thinking

Critical Thinking: A P21 Learning and Innovation Skill that involves "purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation…upon which judgement is based" (Facione, 1990, p. 3).

12. How do you decide if an idea is important?

13. When you have a situation in robotics, how well do you make sure the information is correct?
14. How does your coach help you to make sure an idea is important?
15. In robotics, how does your coach help to make sure to decide if the information is correct?

Teamwork

Teamwork: A skill that includes the expertise that involves "interaction between two or more individuals working together to solve problems" effectively (NCREL & Metiri Group, 2003, p. 47).

16. Thinking about robotics, what does it mean to be a part of a team?
17. In robotics, how do you decide if someone is a good team member?
18. In robotics, how do you decide if someone is a bad team member?
19. Thinking about robotics, tell me about a time that you did not agree with other team members?
20. Tell me about a time in robotics that you listened to the ideas of others even if you disagree with them?
21. Has your coach helped you learn about what it means to be a good team member?
22. How has your coach helped you learn to solve disagreements between team members?
23. Has your coach helped you learn how to listen to the ideas of others even if you disagree with them?

Communication

Communication: Communication: A P21 Learning and Innovation Skill that students demonstrate through expression using various exchanges of information by way of various tools, transmissions, and methods (NCREL & Metiri Group, 2003).

24. Tell me about a time where you had to present in robotics.
25. Has your coach every helped you present in robotics?

Mentor Impact

26. How many coaches do you have in robotics?
27. Have you worked with any of your coaches?
28. What do you like least about your coach?
29. What do you like best about your coach?

NOTE: Additional clarifying prompts may include items similar to the following: "tell me more about…"; "why do you believe…"; and "what happened when…".

Closing: Use the end to discuss the next steps in the research study, including when observations will be conducted.

Student Semi-Structured Interview Protocol (During Competition) – 30-minutes

Greeting: Hello, [insert name]. My name is Jessica, and I am here to talk to you about robotics. I want to begin by thanking you for participating in this interview today. Throughout this interview, I will be asking you questions about your journey in robotics. At the end of the interview, I will leave time to discuss the next steps in this study. If, at any point, you have questions, please don't hesitate to ask. Before we begin, do you have any questions?

To begin this interview, this will be conversational (e.g., how are you?). Before we start, I want to get to know more about you.

Questions

Demographics

1. How is competition going?
2. What do you find most fun?
3. What do you find the least fun?

Problem-Solving

Troubleshooting: Although there are many styles and types of problem-solving techniques, for this study, the style of problem-solving reflects the teachings that are commonly seen in STEM education. More specifically, problem-solving is the ability and skill to unravel different situations that are unfamiliar and to make decisions about the best sequence of action through creativity, collaboration, or resourcefulness (P21, 2009).

4. How do you solve problems during competition? How do you prepare for problems that you don't expect during competition?
5. Walk me through a situation where you had to follow steps in competition to get something done?
6. When facing a problem in competition, how do you decide which answer is best?
7. How does your coach help you solve problems in competition?
8. Tell me about a time your coach helped you follow steps to get things done in competition?
9. When facing a problem, how does your coach help you decide which answer is best in competition?

Critical Thinking

Critical Thinking: A P21 Learning and Innovation Skill that involves "purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation…upon which judgement is based" (Facione, 1990, p. 3).

10. How do you decide if an idea is important in competition?
11. When you have a situation in competition, how well do you make sure the information is correct?
12. How does your coach help you to make sure an idea is important in competition?

13. In competition, how does your coach help to make sure to decide if the information is correct?

Teamwork

Teamwork: A skill that includes the expertise that involves "interaction between two or more individuals working together to solve problems" effectively (NCREL & Metiri Group, 2003, p. 47).

14. Thinking about competition, what does it mean to be a part of a team?
15. In competition, how do you decide if someone is a good team member?
16. In competition, how do you decide if someone is a bad team member?
17. Thinking about competition, tell me about a time that you did not agree with other team members?
18. Tell me about a time in the competition that you listened to the ideas of others even if you disagree with them?
19. Has your coach helped you learn about what it means to be a good team member during competition?
20. How has your coach helped you learn to solve disagreements between team members during the competition?
21. Has your coach helped you learn how to listen to the ideas of others even if you disagree with them during competition?

Communication

Communication: Communication: A P21 Learning and Innovation Skill that students demonstrate through expression using various exchanges of information by way of various tools, transmissions, and methods (NCREL & Metiri Group, 2003).

22. Do you have to speak to the judges during the competition?
23. Has your coach every helped you speak to judges in competition?

Mentor Impact

24. Is your coach helpful during competition?

NOTE: Additional clarifying prompts may include items similar to the following: "tell me more about…"; "why do you believe…"; and "what happened when…".

Closing: Use the end to discuss the next steps in the research study, including when observations will be conducted.

Student Semi-Structured Interview Protocol (Post-Competition) – 30-minutes

Greeting: Hello, [insert name]. I am here to wrap up our conversation about robotics. I want to begin by thanking you for participating in this interview today. Throughout this interview, I will be asking you questions about your journey in robotics. At the end of the interview, I will leave time to discuss the next steps in this study. If, at any point, you have questions, please don't hesitate to ask. Before we begin, do you have any questions?

To begin this interview, this will be conversational (e.g., how are you?). Before we start, I want to get to know more about you.

Questions

Demographics

1. Are you still interested in robotics?
2. What will you miss the most?

Problem-Solving

Troubleshooting: Although there are many styles and types of problem-solving techniques, for this study, the style of problem-solving reflects the teachings that are commonly seen in STEM education. More specifically, problem-solving is the ability and skill to unravel different situations that are unfamiliar and to make decisions about the best sequence of action through creativity, collaboration, or resourcefulness (P21, 2009).

3. What has robotics taught you about problem-solving and troubleshooting?
    - Can you give me an example?
4. What has your coach taught you about problem-solving and troubleshooting?

Critical Thinking

Critical Thinking: A P21 Learning and Innovation Skill that involves "purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation…upon which judgement is based" (Facione, 1990, p. 3).

5. Tell me about your favorite idea in robotics?
    - Why was it your favorite?
6. Tell me about your favorite idea that your coach had?
    - Why was it your favorite?

Teamwork

Teamwork: A skill that includes the expertise that involves "interaction between two or more individuals working together to solve problems" effectively (NCREL & Metiri Group, 2003, p. 47).

7. What did you learn from your team?
8. What will be your favorite team memory?
9. What did you learn from your coach about teamwork?

Communication

Communication: A P21 Learning and Innovation Skill that students demonstrate through expression using various exchanges of information by way of various tools, transmissions, and methods (NCREL & Metiri Group, 2003).

10. What will you do with your design journal?

<u>Mentor Impact</u>

11. What will you miss about your coaches?

NOTE: Additional clarifying prompts may include items like the following: "tell me more about…"; "why do you believe…"; and "what happened when…".

Closing: Use the end to discuss the next steps in the research study, including when observations will be conducted.

<u>Mentor Semi-Structured Interview Protocol (Pre-Competition) – 30-minutes</u>

Greeting: Hello, [insert name]. My name is Jessica, and I will be facilitating our conversation over the next 30 minutes. I want to begin by thanking you for participating in this interview today. Throughout this interview, I will be asking you questions about your journey as a robotics coach. At the end of the interview, I will leave time to discuss the next steps in this study. If, at any point, you have questions, please don't hesitate to ask. Before we begin, do you have any questions?

To begin this interview, this will be conversational (e.g., how are you?). Before we start, I want to get to know more about you. Can you please tell me about who you are? Feel free to include any background information that you believe is pivotal to help me understand who you are.

Questions

<u>Demographics</u>

1. Tell me about your background in STEM, both in general and in STEM coaching.
2. How long have you been involved in this robotics program?
3. Why are you involved?
4. What do you do for a living?
5. What do you like least about being a coach?
6. What do you like most about being a coach?

<u>Problem-Solving</u>

Problem-Solving: Although there are many styles and types of problem-solving techniques, for this study, the style of problem-solving reflects the teachings that are commonly seen in STEM education. More specifically, problem-solving is the ability and skill to unravel different situations that are unfamiliar and to make decisions about the best sequence of action through creativity, collaboration, or resourcefulness (P21, 2009).

7. How do you help students learn to solve unexpected problems or find new or better ways to do things?
8. How well do you help students follow steps to get things done?
9. How do you help students learn trial and error to figure out if something is going to work or not?
10. How do you help students determine the best way to handle a problem?

Critical Thinking

Critical Thinking: A P21 Learning and Innovation Skill that involves "purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation…upon which judgement is based" (Facione, 1990, p. 3).

11. How do you know if an idea is relevant?
12. How do you make sure the information is correct?
13. How do you help students determine if an idea is relevant?
14. How do you help students to make sure all the information is correct?

Teamwork

Teamwork: A skill that includes the expertise that involves "interaction between two or more individuals working together to solve problems" effectively (NCREL & Metiri Group, 2003, p. 47).

15. How well do you help students learn as a team?
16. How do you help your students solve disagreements between team members?
17. How do you help students get along with others?
18. How do you help students listen to the ideas of others even when they disagree with them?

Communication

Communication: A P21 Learning and Innovation Skill that students demonstrate through expression using various exchanges of information by way of various tools, transmissions, and methods (NCREL & Metiri Group, 2003).

19. How do you help students present to a group?
20. How well do you help students express their thoughts on a problem?

Mentor Semi-Structured Interview Protocol (During Competition) – 30-minutes

Greeting: Hello, [insert name]. My name is Jessica, and I will be facilitating our conversation over the next 60 minutes. I want to begin by thanking you for participating in this interview today. Throughout this interview, I will be asking you questions about your journey as a robotics coach. At the end of the interview, I will leave time to discuss the next steps in this study. If, at any point, you have questions, please don't hesitate to ask. Before we begin, do you have any questions?

To begin this interview, this will be conversational (e.g., how are you?). Before we start, I want to get to know more about you. Can you please tell me about who you are? Feel free to include any background information that you believe is pivotal to help me understand who you are.

Questions

Demographics

1. How is competition going?
2. What do you find the most fun? What do you find the least fun?

Problem-Solving

Problem-Solving: Although there are many styles and types of problem-solving techniques, for this study, the style of problem-solving reflects the teachings that are commonly seen in STEM education. More specifically, problem-solving is the ability and skill to unravel different situations that are unfamiliar and to make decisions about the best sequence of action through creativity, collaboration, or resourcefulness (P21, 2009).

3. During the competition, how do you help students learn to explain unexpected problems or discover new ways?
4. During the competition, how well do you help students follow steps to get things done?
5. During the competition, how do you help students learn trial and error to figure out if something is going to work or not?
6. During the competition, how do you help students determine the best way to handle a problem?

Critical Thinking

Critical Thinking: A P21 Learning and Innovation Skill that involves "purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation…upon which judgement is based" (Facione, 1990, p. 3).

7. During the competition, how do you know if an idea is relevant?
8. During the competition, how do you make sure the information is correct?
9. During the competition, how do help students determine if an idea is relevant?
10. During the competition, how do you help students to make sure all information is correct?

Teamwork

Teamwork: A skill that includes the expertise that involves "interaction between two or more individuals working together to solve problems" effectively (NCREL & Metiri Group, 2003, p. 47).

11. During the competition, how well do you help students learn as a team?
12. During the competition, how do you help your students solve disagreements between team members?
13. During the competition, how do you help students get along with others?

14. How do you help students listen to the ideas of others even when they disagree with them during competition?

Communication

Communication: A P21 Learning and Innovation Skill that students demonstrate through expression using various exchanges of information by way of various tools, transmissions, and methods (NCREL & Metiri Group, 2003).

15. How do you help students present to judges?
16. During the competition, how well do you help students express their thoughts on a problem?

Mentor Semi-Structured Interview Protocol (Post-Competition) – 30-minutes

Greeting: Hello, [insert name]. I want to begin by thanking you for participating in this interview today. Throughout this interview, I will be asking you questions about your journey as a robotics coach. At the end of the interview, I will leave time to discuss the next steps in this study. If, at any point, you have questions, please don't hesitate to ask. Before we begin, do you have any questions?

To begin this interview, this will be conversational (e.g., how are you?). Before we start, I want to get to know more about you. Can you please tell me about who you are? Feel free to include any background information that you believe is pivotal to help me understand who you are.

Questions

Demographics

1. Are you still interested in robotics' coach?
2. What will you miss the most?

Problem-Solving

Problem-Solving: Although there are many styles and types of problem-solving techniques, for this study, the style of problem-solving reflects the teachings that are commonly seen in STEM education. More specifically, problem-solving is the ability and skill to unravel different situations that are unfamiliar and to make decisions about the best sequence of action through creativity, collaboration, or resourcefulness (P21, 2009).

3. What do you hope robotics has taught the students about problem-solving and troubleshooting?
    - Can you give me an example?
4. What do you hope you have taught you about problem-solving and troubleshooting?

Critical Thinking

Critical Thinking: A P21 Learning and Innovation Skill that involves "purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation…upon which judgement is based" (Facione, 1990, p. 3).

5. Tell me about your favorite idea in robotics?
    - Why was it your favorite?
6. Tell me about your favorite idea that you had to help the students?
    - Why was it your favorite?

Teamwork

Teamwork: A skill that includes the expertise that involves "interaction between two or more individuals working together to solve problems" effectively (NCREL & Metiri Group, 2003, p. 47).

7. What did you learn from your teams?
8. What skill do you hope the students learned about teamwork?
9. What is one way that you helped the students learn about teamwork?

Communication

Communication: A P21 Learning and Innovation Skill that students demonstrate through expression using various exchanges of information by way of various tools, transmissions, and methods (NCREL & Metiri Group, 2003).

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10. What will you do with the design journals?

APPENDIX C. IRB PROTOCOL

PURDUE
UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	MONICA CARDELLA WANG
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	01/31/2019
Committee Action:	**Expedited Approval - Category**(6) (7)
IRB Approval Date	01/31/2019
IRB Protocol #	1812021490
Study Title	But, is it working? Industry involvement in informal elementary STEM Programs: A Collective Case Study
Expiration Date	01/30/2022
Subjects Approved:	100

The above-referenced protocol has been approved by the Purdue IRB. This approval permits the recruitment of subjects up to the number indicated on the application and the conduct of the research as it is approved.

The IRB approved and dated consent, assent, and information form(s) for this protocol are in the Attachments section of this protocol in CoeusLite. Subjects who sign a consent form must be given a signed copy to take home with them. Information forms should not be signed.

Record Keeping: The PI is responsible for keeping all regulated documents, including IRB correspondence such as this letter, approved study documents, and signed consent forms for at least three (3) years following protocol closure for audit purposes. Documents regulated by HIPAA, such as Authorizations, must be maintained for six (6) years. If the PI leaves Purdue during this time, a copy of the regulatory file must be left with a designated records custodian, and the identity of this custodian must be communicated to the IRB.

Change of Institutions: If the PI leaves Purdue, the study must be closed or the PI must be replaced on the study through the Amendment process. If the PI wants to transfer the study to another institution, please contact the IRB to make arrangements for the transfer.

Changes to the approved protocol: A change to any aspect of this protocol must be approved by the IRB before it is implemented, except when necessary to eliminate apparent immediate hazards to the subject. In such situations, the IRB should be notified immediately. To request a change, submit an Amendment to the IRB through CoeusLite.

Continuing Review/Study Closure: No human subject research may be conducted without IRB approval. IRB approval for this study expires on the expiration date set out above. The study must be close or re-reviewed (aka continuing review) and approved by the IRB before the expiration date passes. Both Continuing Review and Closure may be requested through CoeusLite.

Unanticipated Problems/Adverse Events: Unanticipated problems involving risks to subjects or others, serious adverse events, and serious noncompliance with the approved protocol must be reported to the IRB immediately through CoeusLite. All other adverse events and minor protocol deviations should be reported at the time of Continuing Review.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

Assent Form

Project Title: BUT, IS IT WORKING? INDUSTRY INVOLVEMENT IN INFORMAL ELEMENTARY STEM PROGRAMS. A COLLECTIVE CASE STUDY

Investigator(s): Dr. Monica Cardella, professor of Engineering Education at Purdue University and Jessica Rush Leeker, a Ph.D. student in Engineering Education at Purdue University

We are doing a research study. A research study is a special way to find out about something. We want to find out how students think and feel about math, science, engineering, and technology. Also, we want to see how comfortable students are to learn science, technology, engineering, and mathematics with the help of the robotics mentor. Your parent or guardian has said it was okay for you to be in this research study.

You can be in this study if you want to. If you want to be in this study, you will be asked some questions about yourself, about science, technology, engineering, and mathematics, about robotics, and your mentor for an hour each during three sessions, for a total of three hours.

We want to tell you about some things that might happen to you if you are in this study. You might feel nervous about answering correctly, but there are no wrong or incorrect answers.

If you decide to be in this study, some good things might happen to you. You will receive a children's book at the end of the study. You might understand why you are interested in robotics. But we don't know for sure that these things will happen. We might also find out things that will help other children someday.

When we are done with the study, we will write a report about what we found out. We won't use your name in the report. We will destroy all records three years after the closure of the study.

You don't have to be in this study. You can say "no," and nothing bad will happen. If you say "yes" now, but you want to stop later, that's okay too. No one will hurt you or punish you if you want to stop. All you have to do is tell us you want to stop.

If you want to be in this study, please sign your name.

I, ______________________________________, want to be in this research study.
(write your name here)

_______________________________________ __________________
Investigator signature

Parental Consent Form

BUT, IS IT WORKING? INDUSTRY INVOLVEMENT IN INFORMAL ELEMENTARY STEM PROGRAMS. A COLLECTIVE CASE STUDY

Dr. Monica E Cardella

Engineering Education

Purdue University

Key Information

Please take the time to review this information carefully. This is a research study. Your child's participation in this study is voluntary, which means that your child may choose not to participate at any time without penalty or loss of benefits to which your child is otherwise entitled. Your child may ask questions to the researchers about the study whenever your child would like. If your child decides to take part in the study, you will be asked to sign this form, be sure you understand what your child will do and any possible risks or benefits.

The researcher is a doctoral student at Purdue University in the School of Engineering Education. She is interested in understanding the impact industry mentors can have as they work with children in informal STEM programs. This research project will take place from January to May, with one or two meetings every month.

We would like to interview your child three times and estimate that each interview will last approximately 60 minutes. Therefore, your child will spend a total of three hours participating in this study (beyond the time we spend observing your child's team's normal activities).

Purpose of the Study

The purpose of this study is to explore the impact industry mentor involvement in informal STEM programs at TechPoint sites, and how the program and the mentors impact the children who participate in the program. Your child is invited to be in the study because they are in elementary school, participate in an afterschool STEM program, and are between the ages of 7-12. For this study, we would like to enroll 100 people.

What will I do if I choose to be in this study?

Between January and May, the researcher will attend the weekly program meetings to observe how your child participates in the program and observe how your child interacts with the mentor(s). The researcher will take notes on the program activities and will video-record the team's meetings. Your child will also be interviewed pre-competition, during the competition, after the competition. During this interview, your child will provide basic information (age, gender, race) and be asked about experiences with the TechPoint program. The interview will be audio-recorded. The researcher will also take notes during the interview. Your child will need to agree to participate in the study and sign an assent form.

How long will I be in the study?

Your child will be in the study as long as your child's team continues to meet in the spring of 2019. Once your child's team has completed their competition(s), we will conduct the interview, and your child will be finished with participation in this study.

What are the possible risks or discomforts?

The risk associated with participating in this research is minimal; it is no greater than the risk your child would encounter in daily life.

Breach of confidentiality is always a risk with data, but we will take precautions to minimize this risk as described in the confidentiality section.

Are there any potential benefits?

While there are no direct benefits to the participants, your child may enjoy being interviewed and having the opportunity to reflect on experiences. In addition, your child may benefit by understanding the kinds of outcomes that are valued within STEM-developing those outcomes may help them remain interested in, engaged, and success in STEM. You may better understand STEM practices and assist your child in the development of STEM skills. There may be additional benefits to society. The data collected during this research may be developed into publications, academic journals, or for presentation at professional conferences.
The findings from this study may be used to improve informal STEM programs.

Will I receive payment or other incentive?

Your child will receive a copy of the children's book, The World is So Wide.

Will information about me and my participation be kept confidential?

This project's research records may be reviewed by TechPoint Foundation, the US DHHS Office for Human Research Protections, and by departments at Purdue University responsible for regulatory and research oversight.

Your child's identity will be kept confidential at all times and will be known only to members of the research team. The interview will be audio-recorded and later transcribed. Observations will be video recorded and then transcribed. When transcribing the recordings, pseudonyms (i.e., false names) will be used for your child and for the names of any other people whom they mention. These pseudonyms will also be used in preparing all written reports of the research. Any details in the interview recordings that could identify your child, or anyone your child mentions, will also be masked during the transcription process. After the transcription is complete, the interview recording will be stored in a secure online location. Identifiable information will also be removed from any notes made during the interview. The recordings, transcriptions, and notes will be stored until after the research study is complete and will then be destroyed. All paper data (consent forms, reflections, will be stored in a secured storage space in Wang Hall (Office building of Cardella and Rush Leeker) at Purdue University. Accessibility will be limited. This key will be stored separately from the participants' completed data documents.

Data (including digital audio recordings of interviews) will be stored on a password-protected server. Access will be limited to the project personnel that is approved on the IRB protocol. Records will be destroyed three years after the closure of the study. Although we will remove individually identifying information about participants, we will release site-specific data to our partners at TechPoint.

What are my rights if I take part in this study?

Your child is free to withdraw from participation at any time without prejudice, penalty, or any other negative consequences. Your child's involvement will have no impact on your child's relationship with TechPoint.

Who can I contact if I have questions about the study?

If you have questions, comments, or concerns about this research project, you can talk to one of the researchers. Please contact Jessica Rush Leeker (678.361.9632) or Monica E Cardella (765-496-1206). Jessica Rush Leeker is the primary point of contact for this study

To report anonymously via Purdue's Hotline, see www.purdue.edu/hotline

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.
West Lafayette, IN 47907-2114

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

____________________________________ ________________________

Guardian/Parent's Signature Date

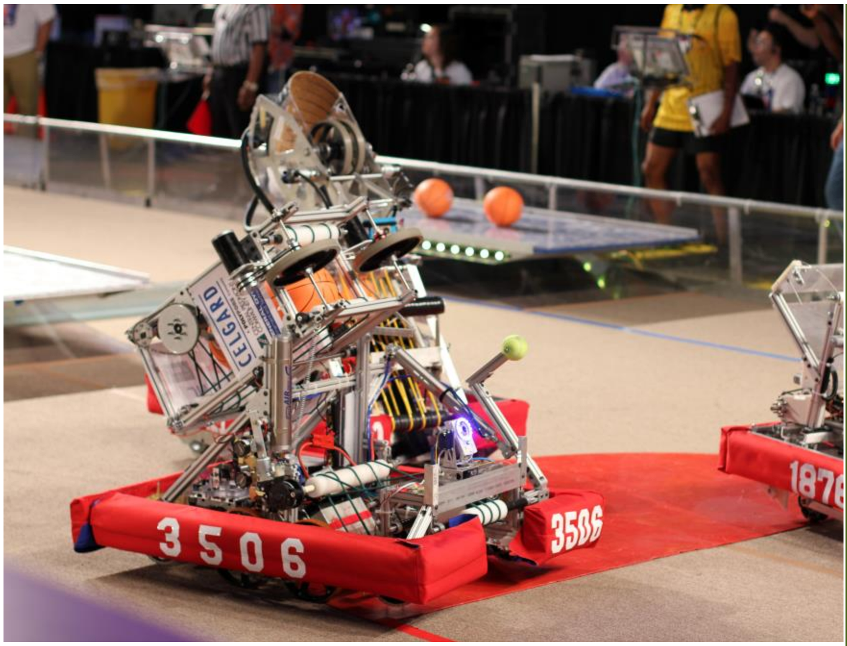
____

Participant's Name

____________________________________ ________________________

Researcher's Signature Date

Recruitment Flyer



You and your child are invited to be in the study if your child:

- In elementary school
- Participate in an afterschool STEM program
- Between the ages of 7-12

Your child will receive a copy of the children's book, The World is So Wide.

IS YOUR CHILD INVOLVED IN ROBOTICS?

VOLUNTEERS NEEDED FOR A RESEARCH STUDY

BUT, IS IT WORKING? INDUSTRY INVOLVEMENT IN INFORMAL ELEMENTARY STEM PROGRAMS. A COLLECTIVE CASE STUDY

The purpose of this study is to explore the future of industry mentor involvement in informal STEM programs at TechPoint sites. The researcher wants to learn about the active participation of industry mentors and student participation at TechPoint, informal STEM programs at after-school elementary robotics program in Indiana.

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JESSICA RUSH LEEKER: RUSH7@PURDUE.EDU

TO PARTICIPATE!

INSPIRE Research Institute for Pre-College Engineering
TECHPOINT FOUNDATION FOR YOUTH™
Growing Indiana's Future

PURDUE UNIVERSITY
Engineering Education

REFERENCES

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