INTEGRATION OF ENGINEERING IN A MIDDLE GRADE MATHEMATICS CLASSROOM: A CONCEPTUAL FRAMEWORK FOR SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS (STEM) INTEGRATION

by

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ABSTRACT

PREMKUMAR PUGALENTHI. Integration of engineering in a middle grade mathematics classroom: A conceptual framework for science, technology, engineering and mathematics (STEM) integration. (Under the co-direction of Dr. DAVID K. PUGALEE and DR. MICHELLE STEPHAN)

In recent years, student centered approaches to learning has gained interest especially STEM based learning. It has led to educational policy and standards reforms including the Next Generation Science Standards (NGSS), which helps teachers, incorporate Engineering and Technology into Science education. Generally, Engineering and Technology practices and principles are extrapolated from collegiate level to P-12 classrooms with limited understanding of what is developmentally appropriate for younger students. This research proposes a re-conceptualized approach to STEM integration using systems thinking that shows the natural connections between the individual subjects, Science, Technology, Engineering and Mathematics. The whole goal is to mimic not only the content knowledge, but also the skills and practices of the real world in P12 classrooms. This design research was conducted in a Grade 7 classroom of a suburban school. Analysis of student pre-interviews revealed that the students possess a rudimentary understanding of engineering thinking and parallel lines and lack a conceptual understanding of angles. These notions were used to design and develop mathematical instructional tasks with an engineering problem as the context in order to motivate students understanding to more sophisticated notions of angles and parallel lines. The post-interview analysis shows an improvement in the students' understanding of angles, parallel lines and engineering thinking. The following STEM practices emerged from the classroom when the students engaged in the engineering based mathematical instructional sequences, (a) developing conceptual understanding in multiple subject areas; (b) building relationships among subject areas; (c) shifting back and forth between goals of the individual subject experts; (d) developing ethical thinking; and (e) rethinking communication.

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DEDICATION

To my late Grandma, Palaniammal for teaching me to be kind, be patient, be dedicated, be passionate and love unconditionally.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

CHAPTER 1: INTRODUCTION

Today's world is becoming increasingly complex with engineering and technological advancements dictating the need for future generations to be prepared to work in jobs that do not exist in the present time. In the competitive world, America's' future scientists, technologists, engineers, and mathematicians must be prepared to remain effective and efficient through re-energized attention to Science, Technology, Engineering and Mathematics (STEM) education (Wang, Moore, Roehrig, & Park, 2011).

STEM education is associated with the development of a broad set of skills including creativity, collaboration, critical thinking, problem solving, scientific reasoning, and spatial skills among students (Berry, Bull, Browning, Thomas, Starkweather, & Aylor, 2010). A STEM focus generating more opportunities for experiential learning can be attributed to the movement from teacher-centered traditional instruction to student-centered instruction (Meyer, Turner, & Spencer, 1997).

Recent educational reforms push for such student-centered pedagogical practices and include curriculum frameworks with high standards, and new approaches to assessment that are aligned to those high standards which in turn demand new innovative approaches in classrooms. In-service teachers are not prepared for teaching in such a high-stakes environment (Garet, Porter, Desimone, Birman & Yoon, 2001) especially when they are not trained in engineering and technology content and skills.

Currently, STEM integration involves using engineering/technology as pedagogical tools and/or engineering as a standalone subject. The primary reasoning for engineering/technology-based education is that it plays a major role in providing an environment that allows a student to investigate, scaffold, collaborate, and reflect on the content they are learning (Tamim & Grant, 2013), which helps to improve students' engagement and performance (Creghan & Adair-Creghan, 2015).

In spite of such benefits, P-12 mathematics classroom tend to incorporate less engineering and technology when compared to science classrooms. Most of the existing engineering integration activities and lesson plans for classrooms focus on the Engineering Design Process (EDP) among the engineering practices. This focus on the engineering design process makes engineering/technology integration more applicable in science than mathematics because of similarities between EDP and scientific method.

Statement of the Problem

As stated earlier, although recent reforms such as the Next Generation Science Standards (NGSS) and Common Core State Standards for Mathematics (CCSSM) encourage integration of engineering and technology in science and mathematics, teachers lack the content knowledge in engineering and practices. The biggest challenge in K-12 STEM education is that few general guidelines or models exist for teachers to follow regarding how to teach STEM concepts (Kimmel, Carpnelli, & Rockland, 2007).

Huffman, Thomas and Lawrenz (2003) explore the role of professional development in science and mathematics education and points out that teachers from education departments have pedagogical skills, yet lack content knowledge. Conversely, teachers from science and mathematics departments have the necessary content knowledge, but lack pedagogical knowledge. This notion can be extended to engineering and technology content knowledge as well.

According to Wang, Moore, Roehrig and Park, 2011, teachers will integrate STEM in a manner that is most comfortable to them. The National Research Council (NRC, 2014) argues that STEM integration is not teaching the individual subjects Science, Technology, Engineering and Mathematics that make up the acronym nor attempting to match the essential standards among these subjects, which are the commonly adapted STEM integration strategies in current P-12 education settings.

Another issue with current strategies of STEM integration is the heavy focus on Science and Engineering while Mathematics and Technology are underutilized (NRC, 2014). Educational researchers similarly note that, although STEM education emphasizes integrating science and mathematics with the purpose of improving engineering and technology, it is merely viewed as two subject matters: science and mathematics (Hernandez et al., 2014).

Alternatively, some put greater emphasis on the engineering aspect of STEM and integrate engineering activities into K-12 curriculum (Berry, Bull, Browning, Thomas, Starkweather, & Aylor, 2010; Brown, Newman, Dearing-smith, & Smith, 2014). A majority of engineering interventions are aimed at promoting STEM among students with the hope that they would choose a STEM career in future years, which has driven all the focus on high school students mainly instead of the entire K-12 students.

Berry et al. (2010) acknowledge the naturally existing children's engineering skills and the relationship between engineering, science and mathematics. Several researchers (Brotman & Moore, 2008; Catsambis, 1995; Clewell & Braddock, 2000; Reid & Skryabina, 2003) argue that students must be exposed to engineering in elementary schools because concepts and skills used in engineering, science and mathematics are mostly the same.

Integrating engineering into early grade levels of education is one way of connecting students' learning at school to their lived experiences and to make even the abstract science and math concepts interesting for them (Fantz, De Miranda, & Siller, 2011). Middle school is a crucial place to introduce students to STEM careers because it is typical for students at this age to develop opinions and their perceptions towards their future career options. This informs the need for increased efforts and attention among middle grades to improve their attitude towards STEM education.

In essence, the major issues in current STEM education includes a lack of a genuine STEM integration in schools due to the lack of research-based engineering-focused instructional materials (Singer, Ross and Jackson-Lee, 2016) and the lack of focus on other practices and principles of the engineering/technology than engineering design process that enable more opportunities for integration in mathematics classrooms.

Conceptual Framework

Overall, the set of research studies I propose in this experiment uses the conceptual framework of Vygotsky's Sociocultural Perspective and Blumer's Symbolic Interactionism under the umbrella of Student-Centered Instruction. This research program aims at developing a framework for genuine STEM integration and utilizes the tenets of Karplus and Their Learning Cycles and Learning Trajectories to develop STEM instructional sequences for lessons that are to be implemented at the exploration phase and the application phase of the learning cycle.

At a macro level, this research is situated within the guiding principles of student-centered instruction. Student centered instruction has been in the lingua franca as early as the 1930s. Student centered learning in general refers to a wide variety of learning experiences, instructional approaches, and academic support strategies that are designed to cater to the specific needs, interests, and cultural backgrounds of students in a classroom (Nanney, 2004). This approach challenges many of the beliefs held by school-centric and teacher-centric traditional learning approaches (Brush & Saye, 2000).

From the earlier discussion, it is clear that the pedagogical strategies utilized in STEM are more student centric. It caters to the needs of personalization of disciplinary knowledge to the real world lived experiences of the students. Such personal learning situations have been shown to improve students' academic performance and attitudes towards STEM careers (Creghan & Adair-Creghan, 2015). This can be attributed to the constructivist movement in learning where the interaction between teachers and students and among students facilitate learning.

Student centric learning is often criticized for several reasons including the dominant autonomous learner that indicates autonomous account of learning ignores the historical and social context of educational practices and absenting knowledge (Bernstein, 2004). Mckenna (2013) summarizes the issue of absenting knowledge as

> The pedagogic discourse of each discipline or field has its own intrinsic features and we need to pay attention to these. Student-centered learning, in its singular focus on the students' needs, fails to take sufficiently into account what the discipline 'needs' or, more precisely put, what the knowledge and knower structures of the discipline are and how are these legitimated. (p. 2)

Vygotsky's Sociocultural Perspective

Sociocultural Historic Theory is the name given to psychologist Lev Vygotsky's cognitive development theory also known as Vygotskian approach (Albert, 2012). The fundamental notion of this approach is that cognitive development is a process of transformation from lower mental functions (LMF) to higher mental functions (HMF) and is aided by the social interactions (Vygotsky & Rieber, 1997). It implies that the learning leads development whereas Piaget's Genetic Epistemology implies that development leads learning through stages of development (Gallagher & Reid, 2002).

According to Vygotsky, all learning is mediated using the tools that are developed in the culture (Albert, 2012). The process of development of higher mental functions "involves signs, which are artificially created stimuli whose purpose is to stimulate behavior, to form new reflex connections in the human brain" (p. 7). In essence, using signs and symbols to represent behaviors or objects is *mediation*. For instance, we use signs including mnemonic devices, speech and writing to meditate our behavior indirectly. As Vygotsky stated, sign is a second order stimulus between stimulus and response.

In contrast to Piaget's genetic epistemology (Gallagher & Reid, 2002), Vygotsky believed that learning is not developmentally governed but is the process of developing specific psychological function as a result of one's interaction with others in the environment. In extension of this notion, *zone of proximal development* (ZPD) is the difference between the level of actual development and the potentially possible development or the difference between what one can develop on their own and under guidance from skilled peers.

This understanding gives the ability for the teacher to scaffold and collaborate based on the learner's level of potential. In addition, Vygotsky strongly believed that the language played a major in our thinking process. The same word can mean differently for different cultures. Speech may initially serve the purpose of communication and then it guides the inner or private speech or the formation of thought. Language is powerful tool in the process of cognitive development and Vygotsky thought that there is thinking possible without any language.

Building on the notion of Vygotsky's Socio-cultural historic theory, Lave and Wenger (1991) suggested that learners gain knowledge by actively participating in their learning in contrast to listening to lectures. Learners improve the competence or learn by participating in the socio-cultural activities and *Legitimate Peripheral Participation* starts as an apprenticeship and evolves into situated learning. Socially *situated learning* in authentic environments stimulates learning and is an active process of creating meaning from the real activities of daily living.

Symbolic Interactionism

In contrast to Vygotsky's Sociocultural perspective, Symbolic Interactionism, introduced by George Herbert Mead in 1920s and coined by his student Herbert Blumer, alludes to the notion that interactions among individuals along with the interpretation by the individual results in meaning making. The important idea here is the inclusion of the individual interpretation, which restates the process of gaining knowledge is not just through social interaction but a self-reflection by the individual in response to the social interaction. The main principles of Symbolic Interactionism can be summarized into three important components, *Meaning*, *Language*, and *Thought*. In extension to the three components can be summarized as *people act on something based on the underlying meaning for it, the meaning for something is created by interactions with other people, and the meanings are handled through a process of negotiation within self that is interpretation by the individual* (Blumer, 1969). This notion can be extended to a community of learners when they engage in learning together.

Learning is a sophisticated complex process with several cognitive and social factors in play and Blumer (1969) stated,

> .. the student to catch the process of interpretation through which they construct their actions. This process is not to be caught merely by turning to conditions which are antecedent to the process.. interpretation is being made by the acting unit it terms of objects designated and appraised, meaning acquired, and decisions made, the process has to be seen from the standpoint of the acting unit (p. 70).

Within this construct, the STEM practices that are realized in the classroom by the students emerge because of the interaction with one another through genuine argumentation (Rasmussen & Stephan, 2008). The idea here is that the community of learners that is students in the classroom working in small groups or the whole classroom through a series of back-and-forth communication infer the meaning interpreted by the others and in-turn self-adjust their own meaning until the whole group arrives at a common taken-as-shared meaning (Yackel & Cobb, 1996).

The research program in this proposal aims to capture the emergence of STEM practices when students engage in the instructional sequences designed to elicit those aspects in students. This notion focuses on the social aspects of learning that is the student's' interaction with the instructional sequences and their peers. Hence, the overarching theoretical lenses for the exploration of STEM practices in middle grades mathematics classroom is provided by Blumer's Symbolic Interactionism (Blumer, 1969) and Vygotsky's Sociocultural perspective, where the meaning is created as a result of interaction among people.

Karplus and Thier Learning Cycle

Learning cycle was introduced by Karplus and Thier in 1962 and gained attention with recent focus on an inquiry approach to learning. The idea of learning cycle is situated within Piaget's intellectual developmental theory and comprises three distinct phases: *exploration* - students explore through data collection via open or guided inquiry, *concept invention* - students analyze the data to identify patterns and are introduced to appropriate scientific terminology, and *application* - students apply the newly learnt concept into new setting to reinforce their understanding (Karplus & Thier, 1967).

There are two opportunities to introduce engineering/technology within this learning cycle, one is at the exploration phase and the other is at the application phase. The notion is that a STEM problem can be used to give a context at the exploration phase for the concept invention phase or knowledge from the concept invention phase applied to solve the STEM problem at the application phase. This learning cycle is particularly important for this design experiment as it guides the design of STEM instructional sequences based on the phase of the learning cycle when the lesson is implemented.

Learning Trajectories and Instructional Sequences

Simon introduced the notion of learning trajectory in 1995 and the idea is that students naturally follow developmental progressions in learning a new concept and these developmental paths are called as *learning trajectories*. The purpose is to sequence instruction along these developmental paths to create developmentally appropriate learning environments. Since in majority of the cases, the developmental paths that are used are an educated guess by the subject experts, they are referred to as *hypothetical learning trajectories*.

Learning trajectories comprises of three main parts, *a goal* - the big concepts and skills that are consistent with students thinking and also foster future learning, *developmental progressions* - is the appropriate path to achieve the goal through scaffolded progressions, and *instructional sequences* - tasks/activities aligned to the developmental progressions aimed at fostering a learning environment where students gain the appropriate knowledge and skills. The whole idea is to capitalize the existing knowledge of students and build upon it to develop new knowledge.

As discussed earlier, there is a lack of a conceptual framework for STEM integration in K-12 classrooms, which are developmentally appropriate. Any research in concern with the same must situate itself within a framework that allows researchers to design and develop interventions, which are developmentally appropriate. It is then obvious to design and develop the learning trajectories and its instructional sequences for STEM integration to ensure that the students learn STEM practices in an appropriate path and contribute to the development of a conceptual framework for STEM integration.

Purpose

Arguments above including the lack of complete conceptual framework for STEM integration along with the lack of focus of mathematics during integration beg the need for a development of a framework for engineering education specific to K-12 educational context and also STEM practices that facilitate additional focus on mathematics in the integration process. A genuine conceptual framework of STEM integration should include, logical thinking, model based reasoning and so on, in order to make obvious connection to mathematical systems of practice (Weintrop et al., 2016).

This eventually will lead to more opportunities for STEM integration in mathematics classrooms, as similar to science classrooms. Additionally, proper emphasis must be placed on reading, writing and communication skills within STEM as well which are often not considered as goal within STEM integration. The goal is to design learning trajectories along with cycles of learning to determine developmentally appropriate STEM practices that will eventually comprise the STEM integration framework that mimics the real world knowledge and skill requirements to be an engineer.

The purpose of this research is to contribute to the ongoing dialogue regarding the efficacy of genuine STEM integration. Specifically, this research is aimed at re-conceptualizing STEM integration using a Systems Thinking Approach and develop an effective conceptual framework for STEM integration. In addition, this research explores the emergence of STEM practices in a middle grade mathematics classrooms using classroom design based research approach. The products at the end of this research include a conceptual framework for genuine STEM integration for both researchers and practitioners and the practices that emerged from the classroom.

Research Themes/Questions

The overarching research theme for this study is to design and develop the instructional sequences to realize STEM practices in the middle grade mathematics classroom and eventually develop a conceptual framework for STEM integration. The dissertation is split into three manuscripts, the first manuscript is aimed to identify the gaps in the literature and provide a research summary for K-12 practitioners and administrators. The latter two manuscripts are based on the data from design based research and focuses on the design and development of instructional sequences STEM integration using the proposed Systems Thinking Approach and the emergence of the classroom practices.

The first manuscript (Chapter 2) entitled *Research Summary: STEM in Middle Grades*, explored the existing literature on STEM education specific to middle grades. The common themes explored in the literature includes (a) students: knowledge, attitudes, motivation, and career interests; (b) teachers: preparation, pedagogical practices, and professional development; and (c) schools: curriculum components, after school programs, and assessment. The ideas in STEM integration highlights the lack of a coherent frameworks and guidelines for classroom teachers. This reinforces the problem statement discussed above and validates the need for this research within the middle grade context. The article is published in AMLE Research summaries along with the recommendations for K-12 practitioners and administrators.

The second manuscript (Chapter 3) entitled *Design of Engineering and Mathematics Integrated Instructional Sequences using a Systems Thinking Approach*, conceptualized a prototype framework for STEM integration using Systems Thinking approach. The purpose of this manuscript is to validate the necessity to take an integrated approach in learning the individual subjects in STEM as opposed to the conventional approach of teaching these subjects in silos. This manuscript will explore the design and development of Hypothetical Learning Trajectories (HLT) and instructional sequences.

Additional recommendations for further revision of Hypothetical Learning Trajectories and instructional sequences will be provided for future implementations.

The third manuscript (Chapter 4) entitled *STEM Integration from a Systems Thinking Perspective: Engineering and Mathematical Practices* explored the implementation of Hypothetical Learning Trajectory and Sequences in the middle grade mathematics classroom. The first phase of implementation of designed Hypothetical Learning Trajectories (HLT) and Sequences will be analyzed to determine which components of HLT emerges from the classroom and how these HLT enables and/or constraint the emergence of STEM practices. The following research questions guided this study,

1. What are the classroom STEM practices that emerge as students engage with the instructional sequences and sequence designed based on the STEM integration conceptual framework?
2. How did the instructional sequences and its implementation enable and constrain the emergence of STEM practices in the middle grade mathematics classroom?

The manuscript explores the emergence of the following meta-practices at the classroom and the individual levels when the designed instructional sequence was used, (a) developing conceptual understanding in multiple subject areas; (b) building relationships among subject areas; (c) shifting back and forth between goals of the individual subject experts; (d) developing ethical thinking; and (e) rethinking communication.

Methodology: Design Based Research

The rationale behind choosing design based research approach is the ability to contribute to development of theory and means of that are designed to support that learning that is the educational practice (Plomp & Nieveen, 2007). The research aims to capture the emergence of STEM practices, which is the normative way of using the ideas of STEM practices to interact with others in the classroom. This classroom based design research follows the typical design research cycle of Design, Implement, Analyze, and Revise. Based on this, the phases of the study includes

- Phase 1: Developing a Hypothetical Learning Trajectory (HLT) and associated instructional sequence for a genuine STEM integration
    - Reconceptualization of STEM integration
    - Sketch of HLT and its instructional sequence
- Phase 2: Implementation and Analysis of Student Learning
    - Actual Implementation
    - Analysis of Student Learning
- Phase 3: Conceptual Revisions
    - Revision of Learning Trajectory and instructional sequence
    - Prototype of STEM Integration Conceptual Framework

Setting and Procedures

The experiment along with the data collection for the phase 2 mentioned in the previous section was conducted in a middle grade mathematics classroom in Spring 2018. Specifically, the research was conducted in a 7th grade mathematics classroom of a STEM middle school in Cabarrus County School district. The teacher of the classroom was exposed to the ideas above and was a part of the design team that developed the Hypothetical Learning Trajectory and the instructional sequences. The experiment was a part of the regular classroom instruction and researcher co-taught along with the teacher.

The 7th grade classroom follows the plan of study as prescribed by the school district and Ratios and Proportions and Parallel Lines are the mathematics content that was in focus during Spring 2018. In addition, the students focused on Energy, Forces and Motion in their Science classroom simultaneously and some of those science concepts was utilized as part of the STEM instructional sequences as well. With these basic ideas, initial ideas for the STEM instructional sequences was developed and presented to the design team.

Over five meetings with the design team, the final STEM instructional sequences was developed. Design team members include faculties from various fields of expertise including mathematics education, science, engineering, and the middle grade mathematics classroom teachers. Researcher collaborated with the team in designing and developing one lesson to be used during the exploration phase and one in the application phase of the Karplus and Thier learning cycle.

The developed instructional sequences were implemented in the classroom appropriately. After, each implementation the researcher and the classroom teacher met to discuss the opportunities and challenges in the implementation of that day and the instructional sequences were revised accordingly. At the end of each lesson, a part of the design team met again to discuss and learn from the lesson that was implemented to make appropriate revisions in the subsequent lessons. Each of these lessons in essence are micro-phases of the larger phases discussed above.

After all the developed STEM instructional sequences have been implemented, the design team met again to redesign and redevelop the Learning Trajectories and their corresponding instructional sequences in Fall 2018. At the end of the first complete cycle of this design research, a prototype of a conceptual framework for STEM integration was proposed along with STEM practices as its components in the two manuscripts. This is the scope of this dissertation proposal of this design research but the research can continue into several more cycles until it is optimized and a final conceptual framework can be developed.

Data Corpus and Analysis Methods

Data collection took place over the course of Spring 2018 semester, and consisted of design team meetings recordings, video recordings of the classroom implementation, teacher and student interviews, and document collection including engineer's log. As discussed earlier, the collected data and findings from their analysis will be used in Article 2 and 3. The details below have been summarized into a table in Appendix A for better visual understanding.

Video Recordings of Design Team Meetings

All the three design team meetings including pre-, during- and post-implementation meetings was video/audio recorded. The video/audio recordings were analyzed using a constant comparative method by Glaser and Strauss (1967) where multiple researchers separately analyze all artifacts by letting themes emerge during ongoing data analysis. One data unit will be analyzed to identify common themes and data analysis will be continued to find additional evidence to support or refute that particular theme.

Several of such themes generated from the analysis of design team meetings were triangulated with other sources of data discussed below to verify or counteract the proposed themes that contribute to the development of tenets of prototype conceptual framework for STEM integration. The data analysis was an ongoing process right from the beginning and contributed to the discussion of emergence or constraint of STEM practices when the students engage in designed STEM hypothetical learning trajectory and its instructional sequences.

Video Recordings of Classroom Implementation

During the implementation of the STEM instructional sequences, the small student groups work and the overall lesson were video/audio recorded. This was the major source of data which was analyzed using Toulmin's model of argumentation to capture the STEM practices that emerge when students engage in designed STEM hypothetical learning trajectory and its instructional sequences. Toulmin's model of argumentation provides structure and function of certain parts of an argument and the core of an argument includes three parts: *data*, *claim* and *warrant* (Toulmin, 1969).

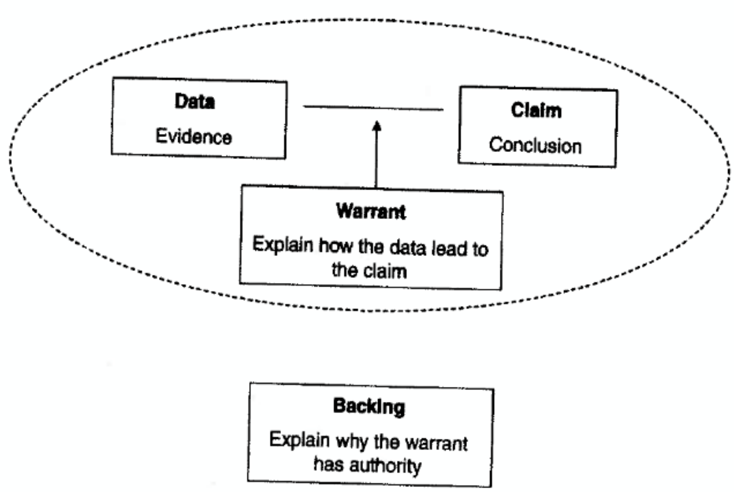

Figure 1. 1: Toulmin's Model of Argumentation (Rasmussen and Stephan, 2008)

In order to make an argument, one has to make a *claim* and support the claim with appropriate *data* or evidence. *Warrant* is providing more clarification to connect the data and claim when the relationship between data and claim is challenged and *backings* are provided to validate the argument when warrant remains implicit (Rasmussen and Stephan, 2008). In addition Rasmussen and Stephan (2008) state, that documenting collective argumentation is not straightforward and several of them is made at the same time. They recommend recording the entire classroom conversation and teasing out necessary information later.

Teacher and Student Interviews

After each of the implementation, the teacher and the researcher met to reflect on that day's implementation. The researcher also conducted an interview with the teacher about specific instances that occurred in the classroom and the specific interview protocol was designed accordingly during implementation. These reflections and interview were aimed to inform further implementations and as data of the progression of the phases for later analysis on emergence of STEM practices. The interview were audio/video recorded.

In addition, small student groups participated in a focus group interview to expand on specific instances that occurred in the classroom that is to ask the student groups to rationalize any specific decisions that the students made when they engaged in the lesson and the specific interview protocol was designed accordingly during implementation. The interviews were audio/video recorded. Both the interviews were analyzed using Toulmin's model of argumentation to capture the STEM practices as mentioned above.

Document Collection

The documents used for the classroom instruction including student worksheets, handouts, rubrics, and engineer's log were collected for additional analysis. The analysis of these documents was aimed at mainly triangulating the findings from the design team meetings recordings, video recordings of the classroom implementation and teacher and student interviews data sets. The documents aided in the implementation of the instructional sequences that were developed by the design team and a sample is shared in Appendix B.

Summary

In summary, the argument is for an integrated approach towards teaching and learning individual subjects in STEM that is Science, Technology, Engineering and Mathematics from a Systems Thinking perspective - these individual subjects are the subsystems of a larger system STEM and learning a new concept in one affects the way of learning another subject. The broader argument is extended to the notion that in spite of obvious connections between Engineering/Technology and Mathematics, it is rather under used in K-12 classrooms when compared to Science classrooms.

The primary reason is the extensive use of Engineering Design Process when it comes to STEM integration in K-12 classrooms. Therefore, the argument for the use of STEM practices that includes additional core concepts/skills of Engineering/Technology, such that there are more opportunities for integrating Mathematics to not only Engineering and Technology but also in Science. Therefore, the purpose of this design research is to design instructional sequences for a 7th grade mathematics classroom to study the emergence of these STEM practices.

CHAPTER 2 [ARTICLE 1]: RESEARCH SUMMARY: STEM IN MIDDLE GRADES

Premkumar Pugalenthi, Alisa Wickliff, David Pugalee

Pugalenthi, P., Wickliff, A., & Pugalee, D. (2019, March). Research Summary: STEM in Middle Grades. *AMLE Research Summaries*. Retrieved May 28, 2019, from http://www.amle.org/Publications/ResearchSummary/TabId/622/ArtMID/2112/ArticleID/1025/STEM-in-the-Middle-Grades.aspx

Tenets of *This We Believe* addressed:

- Students and teachers engaged in active learning
- Curriculum is challenging, exploratory, integrative, and relevant
- Educators use multiple learning and teaching approaches

Science, Technology, Engineering, and Mathematics (STEM) education continues to emphasize the teaching of skills that are relevant to today's information driven economy (Jamali, MdZain, Samsudin & Ebrahim, 2017). Teaching in STEM areas frequently involves real-world problems, problem solving, critical thinking and creativity that enrich student-learning outcomes (Akerson, Burgess, Gerber, Guo, Khan & Newman, 2018; Chalmers, Carter, Cooper & Nason, 2017; Turner 2013). English (2017) argued that STEM has the potential to positively impact student achievement and motivation as long as the integrity of the disciplines is maintained and teachers have the necessary knowledge and resources to effectively implement STEM activities in the classroom. In addition, the research agenda of the Middle Level Education Research Special Interest Group (Mertens, Caskey, Bishop, Flowers, Strahan, Andrews, & Daniel, 2016) included several key components that relate to STEM teaching and learning. These components include a call for development of integrated curriculum research and research in problem-based and project-based learning that is relevant to learners. Related research supports the design, construction, and implementation of simple or complex investigations that are critical to effective STEM learning.

STEM education is a complex idea encompassing multiple content areas and processes including scientific reasoning, computational thinking, engineering design, and mathematical practices (Bybee, 2011). In order to advance STEM learning and teaching, a better understanding of current research is crucial given the high visibility of STEM education and the paucity of research in this area. A comprehensive review of current research in STEM middle grade education focused on three themes: (a) students: knowledge, attitudes, motivation, and career interests; (b) teachers: preparation, pedagogical practices, and professional development; and (c) schools: curriculum components, after school programs, and assessment.

Students: Knowledge, Attitudes, Motivation, and Career Interests

These research studies, focused on students and STEM education, most often discussed how students develop identities (Tan, Calabrese Barton, Kang, & O'Neill, 2013) and their attitudes and self-efficacy towards STEM subject areas and future STEM-related careers (Guzey, Harwell, & Moore, 2014; Hiller & Kitsantas, 2014). Several researchers argued that the reasoning behind the recent move towards STEM education in K-12 schools is to improve students' motivation for learning (Degenhart et al., 2007). Additionally, disparities in STEM performance based on gender (Levine, Serio, Radaram, Chaudhuri, & Talbert, 2015) and learning disabilities (Lam, Doverspike, Zhao, Zhe, & Menzemer, 2008) are highlighted through quantitative and qualitative studies.

Student identities are critical to successful understanding and learning in STEM environments. Jurow (2005) alluded to this notion in her case study research on how students' *figured worlds* influence their approach to mathematical tasks. Jurrow's ethnography and discourse analysis found that designers and facilitators of STEM curricula must realize "students participate and are asked to participate in [multiple figured worlds] when we ask them to engage in projects" (Jurrow, 2005, p.62). These identities shape students' interpretation of the content and practices of the discipline. Jurrow (2005) also highlighted the relevance of understanding student's participation in figured worlds from cultural and historical perspectives.

Kim (2016), using a pairwise *t*-test of 123 female students' pre- and post- attitude surveys for her study Inquiry-Based Science and Technology Enrichment Program (InSTEP), found middle school aged girls' attitudes changed positively toward science when participating in inquiry-based programs. Tan and associates (2013) in their case study explored a related concept—*identities-in-practice* - among non-white middle school girls and their desire for a career in STEM-related fields. By differentiating the narrated and embodied identities-in-practice, the authors highlighted a fundamental issue in our current understanding of the role of identities and learning: "These girls who, on paper, make outstanding science grades and articulate future career goals in STEM-related fields, could be considered exemplary female science students who are 'on track' and who need no special attention, when in fact, they very much do" (p. 1175).

Woolley et al. (2013) reported the importance of using career relevance as an instructional strategy by showing positive effects on mathematics achievement. Their case study looked at how middle grades students used exploratory statistical procedures and multilevel modeling in real-world applications to increase their mathematical understanding. Based on their findings, they recommended school districts focus on improving career developments efforts at the middle level as much as they do at the high school level. Other studies have also supported increasing student awareness of STEM careers for both in- and out-of-school settings in order to improve student motivation and attitudes (Chen and Howard, 2010; & Wyss, Heulskamp and Siebert, 2012).

It is interesting to note that Levine et al. (2015), using a paired *t*-test comparison of pre- and post-camp survey analysis, reported that female students tend to change their ideas about STEM to be more positive and are more willing to perceive themselves in STEM careers after participating in authentic STEM-PBL (Problem-Based Learning) activities. Lam et al. (2008) argued for the inclusive nature of a STEM learning environment by highlighting the positive changes in attitudes and beliefs among middle grades students with learning disabilities based on a paired *t*-test comparison of pre- and post-program surveys. The research studies discussed above highlighted the positive social aspects of project-based learning. At the same time, there are challenges and limitations to using STEM-based pedagogical approaches.

For instance, Mooney and Laubach (2002) researched middle grades students' attitudes and perceptions toward engineering and relevant careers when participating in Adventure Curricula, open-ended and inquiry-based engineering scenarios. Using a *t*-test comparison of pre- and post-program participant surveys, they summarized that students must have prolonged exposure in order to affect their perception and knowledge of engineering. While many of these research studies focused on the social aspects of learning in a STEM environment, cognitive aspects, such as exploring what integrated content and practice is developmentally appropriate for middle grade students, were not discussed.

Teachers: Preparation, Pedagogical Practices, and Professional Development

Commonly discussed research ideas in STEM teaching included the attitudes and perceptions of teachers towards their pedagogical practices (Asghar, Ellington, Rice, Johnson, & Prime, 2012), their beliefs on the role of STEM education within and outside their classrooms (Wang, Moore, Roehrig, & Park, 2011), and the struggle with the open-ended nature of student-centered pedagogy when using STEM PBLs (Lesseig, Nelson, Slavit, & Seidel, 2016). Lessing et al. (2016) in their case study stated that STEM content delivery is successful through open ended, inquiry, PBL-based learning environments that are student-centered instead of the current traditional structures that offer limited opportunities for promoting such instructional strategies. They also argued for the necessity of a paradigm shift by teachers from a transmitter of knowledge to a facilitator of learning

STEM classroom practices are directly correlated to teachers' prior educational experiences and perceptions of the role of their discipline area in STEM. In their case study, Wang et al. (2011) reported that mathematics teachers view STEM integration as a way to provide real-world contexts for mathematical concepts, the science teacher views problem solving as the key in STEM integration, and the engineering teacher views STEM integration as an opportunity to combine problem solving with content knowledge of both science and mathematics. Teachers in all three of these areas had difficulties integrating technology into their classrooms beyond the use of computers as a tool for background research. Lesseig et al. (2016) further stated,

> Teachers had difficulty creating design challenges that were truly interdisciplinary and admitted that the majority of their projects focused on science at the expense of in-depth mathematics, focused on mathematics with only superficial connections to science, or more commonly, focused on the engineering design process with few explicit ties to mathematical and scientific concepts. (p. 183)

The issue was that these teachers did not learn existing connections between and among science, technology, engineering and mathematics. For example, one obvious connection is the use of science and mathematics content knowledge and skills inherent in the engineering and design of everyday technological products such as cell phones. Given the lack of teachers' knowledge of these connections, it is important to make these connections explicit for teachers so they can identify and demonstrate them to their students. Typically, teachers are not academically trained in engineering and technology though they are expected to design and teach STEM lessons that include the T and the E in STEM. One obvious solution recommended to address this problem is providing university-based professional development (Lesseig et al., 2016). Other solutions based on a constant comparative analysis of teacher interviews are providing teachers with time and support for more collaboration with subject area teachers and providing access to experts in developing lessons and activities with clear STEM connections (Stohlmann, Moore, & Roehrig, 2012).

Knezek, Christensen, Tyler-Wood, and Periathiruvadi (2013) in their quasi-experimental design based research focused on improving STEM classrooms recommends "... schools / policymakers / districts / universities should provide additional training opportunities to increase the teaching skills necessary to implement an inquiry-based approach to STEM learning in the classroom" (p. 114). On the other hand, Jordan, DiCicco, and Sabella (2017) in their multiple case study of teachers, found teachers who are content area experts may not be child development experts. Hence, these teachers need additional support in pedagogical aspects such as student-centered instruction, classroom management, and cognitive developments of adolescents. These studies underscore limitations with fast-track alternative certification programs that often reduce exposure to in-depth pedagogical development.

Schools: Curriculum Components, After-School Programs, and Assessment

Research on students and teachers included social aspects of STEM teaching and learning such as attitudes, beliefs, and perceptions towards STEM education, and the factors that influenced them. The central research ideas focused on schools include STEM integration in the disciplines (Guzey, Moore, Harwell, & Moreno, 2016), the different avenues in which STEM-based curricula is utilized with students includes after-school programs (Chittum, Jones, Akalin, & Schram, 2017), summer camps (Mohr-Schroeder et al., 2014), and the nature of assessment when engineering and technology is integrated into science and mathematics classrooms (Harwell et al., 2015).

The curricular aspects of STEM teaching and learning are frequently explored as part of the design of components, programs, and activity involving STEM integration (Wang et al., 2011). Wang et al. (2011) highlighted, "One of the biggest educational challenges for K-12 STEM education is that few general guidelines or models exist for teachers to follow regarding how to teach using STEM integration approaches in their classroom" (p. 2). Currently, STEM integration is explored through approaches that are multidisciplinary (Russo, Hecht, Burghardt, Hacker, & Saxman, 2011), open-ended and inquiry-based (Mooney & Laubach 2002), hands-on (Lam et al., 2008; Knezek et al., 2013; & Levine et al., 2016), project-based learning (Slavit, Nelson, & Lesseig, 2016**),** and use of real-world applications (Bozdin, 2011). Slavit and colleagues (2016) noted in their narrative case study that the role of teachers during innovative school start-ups such as STEM focused schools "...is a complex mixture of learner, risk-taker, inquirer, curriculum designer, negotiator, collaborator, and teacher" (p.14).

Researchers found that teachers faced with integrating STEM in their classrooms lack content knowledge and skills, specifically in engineering and technology subject areas (Jordan et al., 2017; Lesseig et al., 2016; & Wang et al., 2011). In their qualitative analysis of artifacts and videos of classroom implementation, LópezLeiva, Roberts-Harris, and von Toll (2016) recommended collaboration between classroom teachers and university faculty both in the field of education and specific content subjects as a way to bridge the content knowledge and skills gap. Based on their findings, classroom teachers and university faculty collaborated to create MESSY, an integrated teaching and learning experience on motion. MESSY students worked through a process of collective inquiry to co-construct their conceptions of motion. This sub-theme of universities providing support for teachers on content knowledge and research- based STEM pedagogical strategies has been a recurring implication of these studies.

Researchers recommend the use of real-world connections in designing a STEM based curricula. In his mixed-methods study, Bozdin (2011) found that urban classroom learners STEM specific skills such as spatial thinking can be formally taught by incorporating geospatial information technology tools such as GIS and Google Earth. In addition, Hiller and Kitsantas (2014) engaged students in a citizen science program in which students collaborated with naturalists and professional field biologists to study horseshoe crab speciation. Through a series of statistically significant self-efficacy, interest, outcome expectations, and content knowledge measures, they concluded that "providing this type of experience as part of a formal classroom program is a viable means for promoting student achievement and STEM career motivation" (p. 309).

STEM curricula are predominantly used in after-school programs and summer enrichment experiences as a supplementary intervention. In their embedded mixed methods research study, Mohr-Schroeder et al. (2014) listed typical supplementary STEM-based experiences such as field trips, hands-on learning from subject experts, and working collaboratively as a team. Chittum et al. (2017) investigated curricular elements that motivated student engagement at Studio STEM, an after school STEM program. One of the key findings from their mixed-methods study was the importance of presenting information to students in a way that relates to their lives and the real world. Harwell et al. (2015) in their embedded mixed methods research study focused on another area of promise, the development and evaluation of psychometrically sound assessment tools to measure the impact of STEM-oriented instruction. They recommended developing assessments with multiple choice items that are easily scored and include 10 or 15 items per content area including engineering and technology in addition to typical science and mathematics questions.

Conclusion

To date, research has focused on small populations of students, teachers, and schools, generally ala carte STEM programs used as explorations and enrichment. The central research idea involving STEM students is that they must envision themselves as

STEM learners, take ownership of their learning, and engage in learning environments that are meaningful to them and directly relate to possible STEM careers. The literature focusing on teachers highlighted the lack of a proper research-based framework to guide and support STEM integration in an authentic manner instead of adapting it based on teachers' anecdotal evidences. Also emphasized in the literature is the need for teacher preparation and sustainable professional development focused on both STEM content and pedagogy. There is a real and urgent need for research-based STEM frameworks to inform curricular and instructional changes for preservice and in-service teacher education. The major take away from the literature on schools is that both administrators and teachers need to be more purposeful in integrating engineering and technology into mathematics and science classrooms instead of adding supplementary STEM lessons, activities, and programs. The current state of the literature provides middle level educators with a foundation on which to build effective STEM teaching and learning programs that can successfully address the current limitations to meaningful STEM education.

References

Akerson, V. L., Burgess, A., Gerber, A., Guo, M., Khan, T. A., & Newman, S. (2018). Disentangling the meaning of STEM: implications for science education and science teacher education. *Journal of Science Teacher Education*, *29*(1), 1–8.

Asghar, A., Ellington, R., Rice, E., Johnson, F., & Prime, G. M. (2012). Supporting STEM education in secondary science contexts. *Interdisciplinary Journal of Problem-based Learning, 6*(2), 4.

Bodzin, A. M. (2011). The implementation of a geospatial information technology (GIT)-supported land use change curriculum with urban middle school learners to promote spatial thinking. *Journal of Research in Science Teaching, 48*(3), 281–300.

Bybee, R. W. (2011). scientific and engineering practices in k–12 classrooms understanding a framework for k–12 science education. *Science Teacher*, *78*(9), 34–40.

Chalmers, C., Carter, M. L., Cooper, T., & Nason, R. (2017). Implementing "big ideas" to advance the teaching and learning of science, technology, engineering, and mathematics (STEM). *International Journal of Science and Mathematics Education*, *15*(1), 25–43.

Chen, C. H., & Howard, B. C. (2010). Effect of live simulation on middle school students' attitudes and learning toward science. *Educational Technology & Society*, *13*(1), 133–139.

Chittum, J. R., Jones, B. D., Akalin, S., & Schram, Á. B. (2017). The effects of an afterschool STEM program on students’ motivation and engagement. *International Journal of STEM Education, 4*(1), 11.

Degenhart, S. H., Wingenbach, G. J., Dooley, K. E., Lindner, J. R., Mowen, D. L., & Johnson, L. (2007). Middle school students' attitudes toward pursuing careers in science, technology, engineering, and math. *NACTA Journal*, 52–59.

English, L. D. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education*, *15*(1), 5–24.

Guzey, S. S., Harwell, M., & Moore, T. (2014). Development of an instrument to assess attitudes toward science, technology, engineering, and mathematics (STEM). *School Science and Mathematics, 114*(6), 271–279.

Guzey, S. S., Moore, T. J., Harwell, M., & Moreno, M. (2016). STEM integration in middle school life science: student learning and attitudes. *Journal of Science Education and Technology, 25*(4), 550–560.

Harwell, M., Moreno, M., Phillips, A., Guzey, S. S., Moore, T. J., & Roehrig, G. H. (2015). A study of STEM assessments in engineering, science, and mathematics for elementary and middle school students. *School Science and Mathematics, 115*(2), 66–74.

Hiller, S. E., & Kitsantas, A. (2014). The effect of a horseshoe crab citizen science program on middle school student science performance and STEM career motivation. *School Science and Mathematics, 114*(6), 302–311.

Jamali, S.M., Nurulazam Md Zain, A., Samsudin, M.A., & Ale Ebrahim, N. (2017). Self-efficacy, scientific reasoning, and learning achievement in the stem PjBL literature. T*he Journal of Nusantara Studies (JONUS), 2*(2), 29–43.

Jordan, R., DiCicco, M., & Sabella, L. (2017). “They sit selfishly.” beginning STEM educators’ expectations of young adolescent students. *Research in Middle Level Education Online, 40*(6), 1–14.

Jurow, A. S. (2005). Shifting engagements in figured worlds: middle school mathematics students' participation in an architectural design project. *The Journal of the Learning Sciences, 14*(1), 35–67.

Kim, H. (2016). Inquiry-based science and technology enrichment program for middle school-aged female students. *Journal of Science Education and Technology, 25*(2), 174-186.

Knezek, G., Christensen, R., Tyler-Wood, T., & Periathiruvadi, S. (2013). Impact of environmental power monitoring activities on middle school student perceptions of STEM. *Science Education International, 24*(1), 98–123.

Lam, P., Doverspike, D., Zhao, J., Zhe, J., & Menzemer, C. (2008). An evaluation of a STEM program for middle school students on learning disability related IEPs. *Journal of STEM Education: Innovations and Research, 9*(1/2), 21.

Lesseig, K., Nelson, T. H., Slavit, D., & Seidel, R. A. (2016). Supporting middle school teachers’ implementation of STEM design challenges. *School Science and Mathematics, 116*(4), 177–188.

Levine, M., Serio, N., Radaram, B., Chaudhuri, S., & Talbert, W. (2015). Addressing the STEM gender gap by designing and implementing an educational outreach chemistry camp for middle school girls. *Journal of Chemical Education, 92*(10), 1639–1644.

LópezLeiva, C., Roberts-Harris, D., & von Toll, E. (2016). Meaning making with motion is messy: developing a STEM learning community. *Canadian Journal of Science, Mathematics and Technology Education, 16*(2), 169–182.

Mertens, S. B., Caskey, M. M., Bishop, P., Flowers, N., Strahan, D., Andrews, G., & Daniel, L. (Eds.) (2016). The MLER SIG research agenda. Retrieved from http://mlersig.net/mler-sig-research-agendaproject/

Mohr-Schroeder, M. J., Jackson, C., Miller, M., Walcott, B., Little, D. L., Speler, L., ... & Schroeder, D. C. (2014). Developing middle school students' interests in STEM via summer learning experiences: see Blue STEM camp. *School Science and Mathematics, 114*(6), 291–301.

Mooney, M. A., & Laubach, T. A. (2002). Adventure engineering: a design centered, inquiry based approach to middle grade science and mathematics education. *Journal of Engineering Education, 91*(3), 309–318.

Russo, M., Hecht, D., Burghardt, M. D., Hacker, M., & Saxman, L. (2011). Development of a multidisciplinary middle school mathematics infusion model. *Middle Grades Research Journal, 6*(2).

Slavit, D., Nelson, T. H., & Lesseig, K. (2016). The teachers' role in developing, opening, and nurturing an inclusive STEM-focused school. *International Journal of STEM Education, 3*(1), 7.

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated stem education. *Journal of Pre-College Engineering Education Research (J-PEER), 2*(1), 4.

Tan, E., Calabrese Barton, A., Kang, H., & O'Neill, T. (2013). Desiring a career in STEM-related fields: how middle school girls articulate and negotiate identities-in-practice in science. *Journal of Research in Science Teaching, 50*(10), 1143–1179.

Turner, K. (2013). Northeast Tennessee educators' perception of STEM education implementation. (Published doctoral dissertation). East Tennessee State University.

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: teacher perceptions and practice. *Journal of Pre-College Engineering Education Research (J-PEER), 1*(2), 2.

Woolley, M. E., Rose, R. A., Orthner, D. K., Akos, P. T., & Jones-Sanpei, H. (2013). Advancing academic achievement through career relevance in the middle grades: a longitudinal evaluation of CareerStart. *American Educational Research Journal, 50*(6), 1309–1335.

Wyss, V. L., Heulskamp, D., & Siebert, C. J. (2012). Increasing middle school student interest in STEM careers with videos of scientists. *International Journal of Environmental and Science Education, 7*(4), 501–522.

Annotated References

Chittum, J. R., Jones, B. D., Akalin, S., & Schram, Á. B. (2017). The effects of an afterschool STEM program on students' motivation and engagement. *International Journal of STEM Education, 4*(1), 11.

This research on Studio STEM, an afterschool STEM program, explores two different aspects, 1) the student beliefs of science, and 2) the components of the curriculum that motivated students to engage. Both qualitative and quantitative data including science beliefs surveys, studio STEM questionnaire and interviews were analyzed. One of the major findings is that motivational beliefs about pursuing a college degree of the participants of Studio STEM program were more resilient than the control group. The statistical analysis reveals a significant difference in achievement values, perceptions of achievement, and intentions to attend college. Authors also highlight that participation in the STEM program was voluntarily and, hence, the students could already have better beliefs about STEM. One possible solution to rectify this limitation is to compare the pre- and post- beliefs of the same set of students to see if there is a change in beliefs before and after participation.

Mohr-Schroeder, M. J., Jackson, C., Miller, M., Walcott, B., Little, D. L., Speler, L., ... & Schroeder, D. C. (2014). Developing middle school students' interests in STEM via summer learning experiences: See Blue STEM camp. *School Science and Mathematics, 114*(6), 291–301.

The authors of this article use a mixed-methods approach to investigate and report their findings on the changes in middle level students' attitudes, perceptions, and interest in and toward STEM fields and careers before and after participating in a summer STEM camp, an informal learning environment that utilizes STEM pedagogical strategies. The students at the See Blue STEM Camp were exposed to engineering design, visual-spatial reasoning mathematics, neurobiology, environmental sustainability, astronomy, LEGO Robotics, aerospace engineering, mathematical modeling, and neuroscience. The findings include an overall 3.1% increase in middle level students' interest in a career in STEM while comparing their responses in a pre- and post-career survey. Two themes emerged from the qualitative data, C*amp is "fun" and therefore they want to learn more* and camp is *engaging* which further explains the increase in the STEM career interests.

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: teacher perceptions and practice. *Journal of Pre-College Engineering Education Research (J-PEER), 1*(2), 2.

This article compellingly presents the impact of teacher belief systems on their use and integration of engineering in their classroom through directly collected data from the case study. It is evident that teachers will integrate engineering in the manner which is most comfortable to them and that this decision is highly correlated to their beliefs about the value and purpose of STEM integration. Each of the specific cases clearly correlate to the above claim and all case study teachers believe that problem solving is the key to the integration process and technology was the most difficult aspect during STEM integration. The professional development for the teachers that the authors used focused majorly on the student and teachers understanding of engineering design principle and lacks an holistic approach of informing the teachers about the influence of theirs as well as parental and students belief systems on teaching and learning.

Focus on the STEM subjects (2011). [Special Issue]. Middle School Journal, 43(1).

This special themed issue provides practical exemplars of STEM in middle school classrooms. The articles respond to a vision of a challenging, exploratory, integrative curriculum and meaningful learning for students (This We Believe). Articles include examples of STEM integration and discussions about issues in building STEM related skills across the curriculum. Articles include examples of using inquiry-oriented instruction (Hagevik; Longo), promoting the use of real-world STEM connections (Kalchman; Zuercher), developing literacies for STEM contexts (Wood, et al.), and an overview of a STEM program implementation in an entire school (Stohlmann, et al.). The issue takes a special look at engineering with an emphasis on technology tools and content connections to mathematics and science that are used to solve real-world problems that are of interest to bettering humanity.

Recommended Resources

- Engineering Everywhere. https://www.eie.org/engineering-everywhere
- K-12 Resources for Science, Technology, Engineering and Mathematics Education. http://www.nsfresources.org/
- Resources and Downloads for STEM: https://www.edutopia.org/article/STEM-resources-downloads
- Teach Engineering: STEM curriculum for K-12. https://www.teachengineering.org/
- Ten Great STEM Sites for the Classroom. http://www.educationworld.com/a_lesson/great-stem-web-sites-students-classroom.shtml

CHAPTER 3 [ARTICLE 2]: DESIGN OF ENGINEERING AND MATHEMATICS INTEGRATED INSTRUCTIONAL SEQUENCES USING A SYSTEMS THINKING APPROACH

Premkumar Pugalenthi, Michelle Stephan, David Pugalee, Amanda Casto

Introduction

The intricacies of today's technologically advanced world have pushed educators to rethink the set of core skills and knowledge that current students should learn. Included among these skills is problem solving, gathering data, evaluating evidence, making sense of information and communicating findings with others. Science, Technology, Engineering, and Mathematics (STEM) education provides students with opportunities to develop such skills and knowledge and the application of that knowledge (Mahoney, 2010). STEM education started as a way of providing additional rigor and depth for gifted students, but over the years, it has proven effective with a range of students and, in fact, has improved disadvantaged students' motivation and performance (Kim & Law, 2012).

This understanding of the importance and necessity of student-centered approaches has inspired researchers and policymakers to work towards increasing student-learning opportunities in United States (Brown, 2012). Given the emphasis, there is no surprise that there is a huge push for educational standards reforms by organizations such as National Council of Teachers of Mathematics, the National Research Council, and the International Technology Education Association. Recent educational standards reforms such as *Next Generation Science Standards* (NGSS) and *Common Core State Standards for Mathematics* (CCSSM) encourage integration of engineering and technology in science and mathematics classrooms (Kuenzi, 2008).

The underlying intent of these mathematics standards is to enculturate students into the mathematical practices that will encourage deeper understanding of the concepts (cf. Standards for Mathematical Practices, CCSSM) and help students apply mathematics to the world around them (Brown, 2012). STEM-based mathematics learning, at its heart, is an investigative process that allows the learner to dive deeply into a topic and use mathematics to create a solution. A student centric approach like STEM-based learning becomes not only a viable method of teaching and learning, but possibly a highly effective method as well (Bybee, 2010). The central idea with STEM education is promoting pedagogical practices that are student centric. That is, teachers play the role of facilitators as opposed to the traditional knowledge provider.

Teachers employ several instructional strategies including student-led presentations, problem-based learning, brainstorming sessions, small group discussions, simulations, student-led experiments and engineering designs and so on (Fairweather, 2008). In the world of mathematics, STEM-based learning allows students to use mathematics within the context of other subject areas to solve problems. This process requires students to learn math to apply to the formation of a solution or solutions. The math is never separated from other disciplines, thereby making the construction and the application of knowledge easier (Fairweather, 2008). STEM-based learning accesses the students' knowledge and engages students to be part of a community collaborating on activities (Blumenfeld, Krajcik, Marx, & Soloway, 1994).

Thus, students share what they already know with other students in the group toward finding solutions for the tasks. Students discuss, justify, and argue about the mathematics as part of this collaboration. This research paper is a part of a larger research study that aimed to contribute to the ongoing dialogue regarding the efficacy of genuine STEM integration. Specifically, this study explored the process of design and implementation of a classroom-learning trajectory (Stephan, 2014) that integrated mathematics and engineering in an authentic manner to evoke STEM practices more generally. Our goal was to explore the feasibility of using engineering contexts to teach mathematics and to develop a conceptual framework for effective STEM integration. The rationale behind choosing a design based research approach was the ability to contribute to development of theory and educational practices together given that the inter-relation between them is complex and dynamic (Plomp & Nieveen, 2007).

STEM Integration

While there has been a nationwide push to increase STEM in secondary schools, the debate regarding the best practices for integrating STEM across multiple subjects still exists (Stephan, Pugalee, Cline, & Cline, 2016). Therefore, new theories of best integration practices in STEM are still being conceptualized and pursued. One of the greatest challenges facing secondary STEM teachers today is seamlessly and effectively integrating STEM content as well as the related processes into their core classes. A common barrier for this integration is accurately navigating the multiple static components of a STEM curriculum. The introduction of engineering as a critical component of STEM education is especially problematic for educators who have little training or prior skills with engineering content and principles.

Wang, Moore, Roehrig and Park (2011) showed that successful STEM integration is possible using their case study of three middle school teachers. Their important findings included that teachers need more content knowledge especially in engineering and technology and that their STEM classroom practices depend on their perception of the use of STEM integration, which is influenced by their primary discipline. Also, typically mathematics and science is taught first to solve an engineering challenge which gives the impression that mathematics and science are just a tool for solving engineering and technology problems. The purpose of mathematics and science learning is to engage students in more sophisticated conceptual understanding than just the application of sciences and mathematics in other subject areas.

Existing Approaches to Integration in STEM

In the field of education, long before the addition of engineering and technology into the integrated curriculum, science and mathematics integration had been discussed extensively based on the benefits of an interdisciplinary approach (Pang & Good, 2000). Czerniak, Weber Jr, Sandmann, and Ahern (1999), highlight the fundamental problem with science and mathematics integration as, ".... ambiguity is evident in the sheer number of words used to describe integration: interdisciplinary, multidisciplinary, transdisciplinary, thematic, integrated, connected, nested, sequenced, shared, webbed, threaded, immersed, networked, blended, unified, co-ordinated, and fused" (p.422).

Based on a systematic review of science and mathematics integration literature from 1935 to 1997, Hurley (2001) defines integration as

> "from least to greatest level of integration as, *Sequenced*: Science and mathematics are planned and taught sequentially, with one preceding the other; *Parallel*: Science and mathematics are planned and taught simultaneously through parallel concepts; *Partial*: Science and mathematics are taught partially together and partially as separate disciplines in the same classes; *Enhanced*: Either science

or mathematics is the major discipline of instruction, with the other discipline apparent throughout the instruction; and *Total*: Science and mathematics are taught together in intended equality" (p. 263).

These notions of integration can be observed in the STEM curricula that has been developed and used in the last two decades. The major concern is that integration strategies and curricula used are anecdotal evidences based on teacher and curriculum writer experiences. It is interesting to note that the issues faced by science and mathematics integrated curriculum (Pang & Good, 2000) such as over emphasis of one subject area over the other, lack of empirical evidence for effectiveness (conceptual understanding) of integration, teacher preparation and perceptions, lack of empirical research based framework of integration can be attributed to STEM integration as well.

According to the Science Education Resource Center (SERC) at Carleton College (n.d.), interdisciplinary teaching is the "use and integration of methods and analytical frameworks from more than one academic discipline to examine a theme, issue, question or topic." It is different from multidisciplinary teaching, which refers to simultaneous, yet separate, teaching of subjects. Interdisciplinary models of teaching allow students to gain multiple perspectives of a singular topic as well as synthesize the conflicting insights from alternative disciplines. Since multiple content areas are simultaneously being addressed, for the teacher, interdisciplinary models of teaching may alleviate concerns of hegemonic thinking or discourse or the marginalization of subject material because it incorporates multiple foci to a given problem using knowledge from various content areas (Capraro & Jones, 2013).

Although different, interdisciplinary models are commonly referred to as transdisciplinary models of teaching (and vice versa). “True transdisciplinarity goes beyond simply drawing together concepts from the disciplines and that it creates new frameworks that break down (transgress) the traditional boundaries of the disciplines” (Mitchell, 2005, p. 332). Transdisciplinarity is commonly sought after when integrating subjects to create new hybrid frameworks of teaching. Because of their focus on combining subject areas, both interdisciplinary and transdisciplinary teaching methods have been popularly referenced to describe successful STEM integration practices. Literature on STEM integration contain many arguments for adopting interdisciplinary frameworks of teaching.

For example, Capraro and Jones (2013) posit authentic STEM project based lessons (PBLs) are inherently interdisciplinary as they naturally integrate content from the different STEM subject areas. Mayes, Gallant, and Fettes (2018) argue for interdisciplinary STEM teaching as a way to move away from the traditional teaching of these subjects as silos. However, a study conducted by Wilhelm (2014) used the moon for a STEM PBL unit because it is “inherently interdisciplinary,” suggesting that only some STEM concepts are suitable to be taught interdisciplinarily. It is important to note that these existing approaches to STEM integration still do not address the fundamental issue of the tension between the individual subject areas, which is the primary focus in the classroom.

Systems Thinking Approach to STEM Integration

The arguments in the previous sections mainly the ambiguities that the existing approaches to STEM integration creates in classrooms for teachers that are not academically trained in engineering principles and practices beckons the need for newer approach to integrating STEM in K-12 classrooms. This article proposes that, when STEM integrated lessons are based in the notion of systems thinking, the teaching of multiple subjects becomes less rigid. Kelley and Knowels (2016) conceptual framework for integrated STEM education alludes to this idea with their pulley system model. However, they place the emphasis heavily on engineering design and scientific inquiry, which can lead to fewer instances for mathematics and technology to be a central part of the STEM system.

Systems thinking is a sometimes-unfamiliar notion in the field of education though it has been a topic of discussion in K-12 education even before the recent increased focus on STEM education. Betts (1992) points out an important issue with a systems approach as "Unfortunately, the word *system* has been popularized without a fundamental understanding of its implications, to the point where everything is a system but nothing really is treated as one" (p.38). This perspective beckons the questions, *What is systems thinking? And why is it relevant to STEM education specifically?* The notion of systems stems from Von Bertalanffy's (1968) general systems theory through his research on theoretical biology where he argues that the biological systems must be studied as a whole instead of the individual biological mechanisms that are interrelated to one another.

Richmond (1994) coined the term "systems thinking" and defined it as "is the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure" (p.6). The idea is moving away from finding the cause of the problem to fix the problem and, instead, into understanding the nature of the problem and its solution in relationship with other components of the system. The key difference is that the former will fix the problem but new problems can emerge; whereas, the latter would take into account such possibilities while designing the solution (Aronson, 1996). Similarly, approaching integration of STEM from a perspective of understanding its nature will help see the harmonious relationship between the individual subject areas explicitly for the teachers and their students.

For instance let us consider a real world scenario, an aeronautical engineer designing a new model of an aircraft and for doing so, the engineer must use his/her basic knowledge of science including Newton's laws of motion and Bernoulli's principle and mathematics to solve the equations modeled based on those laws. The final product of this engineering is a technology that is an aircraft in this case. This was made possible due to the synergistic understanding of the individual subjects and the pragmatic solution of such integration is something that is useful to better the human lives. This new approach to STEM integration. Guzey, Harwell, and Moore (2014) highlight that one of the reasons of the purposeful integration of different disciplines is to deepen student understanding of particular concepts in one discipline by providing contexts using other disciplines.

Extending the notions of systems thinking to STEM integration, individual subjects can be considered as sub-systems, which relate to each other and they overall relate to the bigger system of STEM. This notion can be extended into P-12 classrooms where students learning of particular content in science can be influenced by their understanding of another content in mathematics. Say, a student is introduced to newton's laws of motion in their science classroom and solving quadratic equations and systems of equations in mathematics classroom, he/she will use those knowledge together in engineering a bottle rocket which is a technology. Below is the detailed correlation between the key concepts of systems thinking to STEM integration,

- *Input and Output*: learning of the new concept by the learners and the instructional sequences used to achieve the same;
- *Process*: the process of meaning making by engaging in the instructional sequences facilitated by the instructor;
- *Environment:* classroom and the school is the environment in which the subsystems that is the individual disciplines are learned;
- *Feedback*: is the synergistic relationship between the individual disciplines;
- *Goal*: understanding of a particular concept by the learners;
- *Subsystems*: the individual disciplines that are being integrated; and
- *Boundaries*: the goals and practices of each discipline that makes them unique.

Comparing and Contrasting to Existing Approaches

The previous section highlighted the issues with the existing approaches to STEM integration. In summary, if the STEM integration takes a *cross disciplinary* approach which views one discipline from the perspective of another will lead to the ignorance of the synergistic relationship between the disciplines; an *multidisciplinary* approach where people from different disciplines working together, each drawing on their disciplinary knowledge will lead to the ignorance of tension that which discipline takes the lead; an *transdisciplinary* approach which creates a unity of intellectual frameworks beyond the disciplinary perspectives will lead to the loss of the essence of individual fields; and an *interdisciplinary* approach that integrates knowledge and methods from different disciplines will lead to an incorrect interpretation that the disciplines overlap with each other when in fact they are just compatible.

These highlight the need for the new approach to STEM integration using the notions of systems thinking must be explicit, intentional and purposeful for teachers that are not academically trained in engineering and technology to help their students understand that the individual disciplines in STEM are compatible with each other yet each discipline is governed by its own set of rules and practices. In order to better visualize this approach, a gear model (Figure 1) is introduced where the larger gears are the individual disciplines and the smaller gears represent the practices and skills including teamwork, communication, data modeling, computational thinking and so on. This gear model also allows the addition of more gears for introducing other disciplines such as arts, social sciences, literacy, humanities and so on and make it a more holistic model which has received less attention in the recent era (Stromquist & Monkman, 2014).

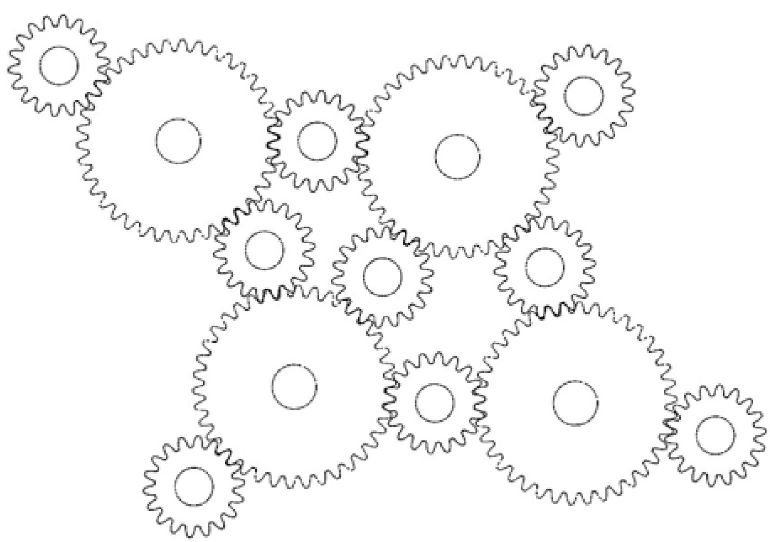

Figure 3. 1: Gear Model for STEM Integration

Inclusion of Additional Disciplines

As mentioned earlier, the creative arts and social sciences have received much less attention in the era of globalization due to a heightened emphasis on subjects assessed through high stakes testing (reading and math) and STEM (Stromquist & Monkman, 2014). Interdisciplinary methods of integration have resulted in the gradual marginalization of non-STEM subjects. Contrary to interdisciplinary integration, the systems thinking approach enhances the unique integrity of subjects such as creative arts and social studies and should be considered when interweaving STEM practices with non-STEM subject matter. The research and development industry would be the first to admit STEM and the creative arts, historically, go hand-in-hand. There is a symbiosis that exists between the arts and sciences; not only do new technologies and products need to be functional, they also need to have aesthetic appeal to increase marketability.

Furthermore, the critical thinking that fuels problem solving also requires various levels of creativity, which naturally spurs artistic ability. For this reason, among others, educational researchers have called for a STEAM (Science, Technology, Engineering, Arts, and Mathematics) integration approach, rather than STEM (Henrikson, 2014). Like STEM, STEAM education should be viewed as an interworking mechanism enhancing students' holistic learning experiences. In addition to the arts, STEM can also enhance social studies. According to the National Council for the Social Studies (NCSS), social studies is the "original STEM." Like STEM, social studies emanates multiple bodies of knowledge in which to view - and operate in - the world (NCSS, n.d.). Instead of trying to meld two vast disciplines by superficial means, however, it makes more sense to integrate STEM practices into social studies lessons with a systems thinking approach.

STEM learning does not occur in a vacuum; it is always impacted by the social contexts that surround students. Therefore, we argue that the various social studies disciplines - civics, economics, geography, and history - are just additional gears in which STEM learning takes place. In the systems thinking approach, STEM integration in the social sciences, or study of humanities, is a naturally occurring process. Since students are motivated to solve real world problems, social studies should not be viewed as a separate subject in which to infuse STEM, but regularly be considered as part of the STEM lesson design. In essence, teaching and learning of the individual subjects that make the acronym STEM must move away from the compartmentalized approach towards an integrated approach of content domains.

Secondly, given the natural similarities between engineering and mathematical practices there is a need for revised standards that consider common pedagogical practices that develop both principles and processes of reasoning. All the individual subjects should be given equal importance in a conceptual framework of genuine STEM integration which in-turn will drive a similar notion to classroom through corresponding pedagogical strategies. Classrooms must be conducive for students to collaborate with each other and engage with problem with a vested interest to find an appropriate solution. Finally, in order to ensure students are STEM literate requires rethinking our subject matter driven approaches and strategies to incorporate models that emphasize the underlying structures of the cognitive processes involved when one engages in true STEM learning. This can happen if systems thinking approaches drive research, policy and practices related to STEM education across P-12 and beyond.

Methodology

As discussed earlier, the compatibility between these different disciplines is unique and this paper focuses on the integration of engineering and mathematics in a middle grades classroom. The research reported in this paper aims to develop a framework for K-12 teachers and instructional designers to purposefully and intentionally design the engineering context based mathematical instructional sequences. The research was conducted in a 7th grade mathematics classroom of a STEM middle school in a suburban school district in the southeast region of United States. The classroom teacher was part of the design team along with faculty specializing in mathematics education, chemistry, and engineering at a large urban university and a mathematics education faculty member from an international university. This research is comprised of a pre-interview to assess the existing conceptions of angles and parallel lines and their engineering thinking, design and implementation of engineering-based instructional sequences, and a post-interview to assess the changes in conceptions of angles and parallel lines and their engineering thinking.

This article focuses on the analysis of the pre- and post-interview questions dealing with angles and parallel lines and engineering thinking to design and develop engineering based mathematics instructional sequences. Before developing the instructional sequences, 4 students (2 male and 2 female students) at different academic performance levels (as identified by the classroom teacher) were interviewed. The student's cumulative performance on prior assessments in their current classroom was used as the criteria to classify the four academic performance levels as *high, above average, average* and *low*. These four students engaged in a pre-interview with questions designed to probe their understanding of angles, parallel lines and their engineering thinking.

The purpose of these pre- and post-interviews was to learn the students' current conceptions of these mathematical and engineering ideas and design the instructional sequences appropriately for the entire classroom. The interview questions probed for the students' conceptual understanding of angles, parallel lines and their engineering thinking. The first angles question prompted the students to identify the biggest and smallest angle from a set of angles represented diagrammatically (Figure 2). The second set of angles questions asked the students to identify the number of angles in various diagrams such as a triangle (Figure 2) and validate their solution with a mathematical argument.

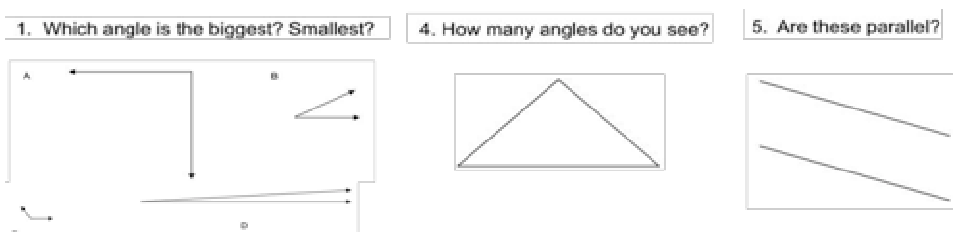

Figure 3. 2: Sample questions from the interview questionnaire

Similarly, the parallel lines questions asked students to identify if the given lines, curves and geometric shapes (e.g., Figure 2) have anything parallel in them and validate their solution with a mathematical argument. Students also provided solution and their rationale for two different scenarios to assess their engineering thinking each in pre- and post-interviews. The students were asked to provide a solution for how to build an underground cavern to escape asteroid impact (Figure 3) based on the given constraints during the pre-interview. Similarly, they provided solution for how to build an lunar station based on the given constraints for the post-interview. After the pre-interview, the design team over five meetings designed and developed engineering based instructional sequences within the framework of systems thinking approach to integration.

**** URGENT CLASSIFIED MEMO****

TO:	THE U.S. SPECIAL ENGINEERING TASK FORCE ON CATASTROPHIC COLLISIONS
FROM:	THE PRESIDENT OF THE UNITED STATES OF AMERICA, MR. HOMER DEBRAVE
SUBJECT:	IMMEDIATE DEPLOYMENT OF SPECIAL ENGINEERING FORCES FOR SITUATION CRITICAL: ASTROID IMPACT CODE NAME: *BIG ROCK* CLEARANCE: R-UN-4-YRL-IVES
DATE:	0600 HOURS, YESTERDAY
CC:	NATIONAL SECURITY ADVISOR, MR. IKE EEPUSAFE, DIRECTOR OF ASTROID RESEARCH, MS. I.C. STARRZ

Figure 3. 3: Sample Memo of the Scenario to Assess Engineering Thinking

In analyzing the student responses and design team meeting, the constant comparative method (Glaser & Strauss, 1967) was utilized in order to identify themes that are grounded within the data. The student and design team justifications were broken down into discrete incidents. Researchers simultaneously coded and analyzed these specific incidents to inductively reason the categories for codes and their properties. Three researchers met and analyzed the student and design team responses from the videos and identified emerging categories as the students communicated his/her mathematical arguments. The analysis also took into account the hand gestures of the students while analyzing the pre- and post-interviews. Select portions of the videos were transcribed later for inclusion in the research. Constantly identifying and comparing the relationships between these categories led to the final themes. Once a theme emerged, data analyses were continued to either support or refute the theme until all the student responses were analyzed. This process was the same for both the angles, parallel lines questions, engineering thinking, and design team meeting but analysis for each topic was performed separately.

Pre-Interview Analysis

This analysis of the students' conceptions of angles, parallel lines, and their engineering thinking comes from the pre-interview data, before instruction with an engineering context to teach the same mathematical concepts. The following three themes emerged from the angles interview analysis: *Using Prototypes or Reference Images, Tracing of the Lines, and Decoupling versus Decomposing.*

Theme One: Using Prototypes or Reference Images

The first theme that emerged from the data analysis was the idea of using prototypes or reference images of angles to identify and define angles. All of the students shared this notion where they used reference images such as 90°-, 180°- and 360°-angles or used the definitions of acute and obtuse angles. The students associated the word 90° or 180° with the diagrammatic representation of the same without any understanding of what it means that a right angle is 90°. For instance, the student below expressed their confusion with straight angle and straight line, likely, as they had seen a straight line referred to as both a straight angle and a straight line in the past.

Student: This is a straight...

Interviewer: Straight what?

Student: It is either straight line or straight angle because this is whole 180.

Theme Two: Angles as Corners

A second theme that emerged from the data analysis was the idea of tracing the line to see if it changes direction as a rationale to identify if there is an angle. For instance, the student below, when asked to identify the number of angles in the given diagrammatic representation of the right triangle in Figure 2, reasoned that there was one angle because there was a corner which makes the line go in two different directions. The student viewed the rays of the angle dynamically in that a dot could be used to trace along one ray and then change direction to follow the other ray, thus, producing an angle. A different student traced the line as well, but the conception of angle was not as dynamic. The student viewed the two lines as two static entities connected at a point to form an angle.

Student: So here's the main line and then it's starting to go up as in 90^0.

Interviewer: Main line is going this way (horizontal), then the other line this way (vertical)

Student: Yes, in a 90^0 angle.

Theme Three: Decoupling versus Decomposing

A third theme was the idea of dissociating the original angle from the two new angles when the original angle is split into two by a new ray. In other words, the students counted the whole angle as an angle and the two new split angles; each as one but they did not worry to check if the sum of the two new angles equals the original angle when they were asked to estimate the angles.

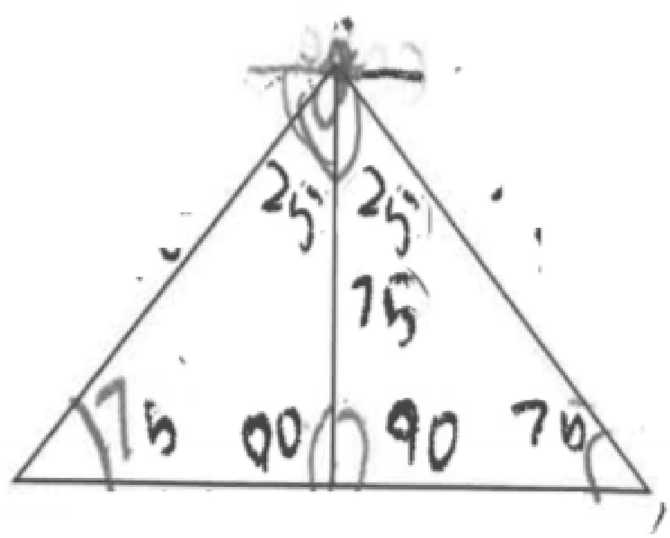

Figure 3. 4: Decoupling of Angles

In Figure 4, the student estimated the three angles of the equilateral triangle to be 75° and then the two split angles on the top to be 25° each. We also observed another case, where the student expressed that the original angle is no longer available when it is split and only the two new angles are left. In other words, they view the new right-angled triangles as a decoupled shape as opposed to decomposing the angle from the equilateral triangle into two right-angled triangles.

The following two themes emerged from the parallel line questionnaire analysis: *Never Touch and Same Shape Pattern.*

Theme One: Never Touch

The first theme that emerged from the data analysis was the idea that something is parallel if they never touch. This is evident in one student's use of railroad tracks as an example. The questionnaire began with sets of lines oriented in different angles and were misaligned the reasoning that they will never touch was predominately used by all students for these questions with lines.

Interviewer: How about these?

Student: Parallel, I see this mainly because they still won't touch.

Theme Two: Same Shape Pattern

Another theme that emerged from the data analysis was the idea that for two lines or curves to be parallel they must have the same shape pattern and align in the same direction. This reasoning of having the same shape pattern emerged only when curves were introduced in the questions (Figure 5).

Interviewer: How do you know that they are never going to touch each other?

Student: As long as this pattern is maintained, they're never going to touch.

However, two of the students extended the curves into a line to show that either the two lines/curves touch or not touch to justify their argument of whether they are or are not parallel. For instance, in Figure 5, the student extended the curve at the bottom as a line to touch the straight line on the top instead of following the pattern of the curve at the bottom. This shows that the students preferred the never touch rule over the same shape pattern when justifying their argument as to whether they are or are not parallel.

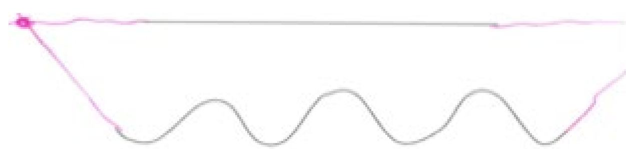

Figure 3. 5: Parallel Lines/Curves Never Touch

From our analysis of students' existing notions of parallel lines, the students' mathematical arguments were rudimentary and based on their prior experiences of parallel lines either in mathematics or other subject areas. This is evident in the classic railroad track example followed by the justification that the two tracks never touch. Students demonstrated difficulty in extending the notion of the lines that never touch to more sophisticated notions such as that the lines are equidistant from each other.

The following four themes emerged from the engineering thinking questionnaire analysis: *Design Process, Ethical Considerations, Relational Design, and Collaboration*.

Theme One: Design Process

The first theme that emerged from the data analysis is the students rudimentary understanding of the design process. These students have prior exposure to the engineering design process; however, they did not explicitly state the design process but all of the students followed a logical structure in figuring out a solution to the problem. For instance, they started of by identifying the constraints in the given memo/brief and justified each selection with a rationale as to why it would affect their design. However, they all alluded to build their final cavern without any prototype design and testing.

Interviewer: You have highlighted, "An asteroid with one mile diameter headed towards earth". Why did you highlight that?

Student: Because, if you know the diameter... when it hits you can know how big it (crater) is

Interviewer: And why do you need to know that?

Student: That then you know how far the cave must be built in.

Theme Two: Ethical Considerations

The second theme that emerged from the data analysis is the students ability to be think ethically while making design decisions. For instance, the student below highlights that there needs to be multiple entry points to the caverns so people from across the different locations can access it easily, mainly the elderly and the sick. The design discussions could have been simply about the strength and the capacity of the caverns but three students rationalized their design that were socially conscious. It is interesting to note that one of the students design choices was primarily influenced by his/her idea to save all of the population with no or limited casualties (idealistic philosophical orientation), while the another's design was to save as many people as possible given that the time to build the caverns for one million people in 10 days (pragmatic philosophical orientation).

Interviewer: How would it help you to think about the bigger problem if I give you this (hands the map) general map of the location?

Student: Ok so, major highways, railroad, rivers, fault lines, military base, airport…. We can build an opening (to the cavern) near the highways and railroad so people with different needs can easily access the caverns. Some people are elderly and some are in hospitals….

Theme Three: Relational Design

The third theme that emerged from the data analysis is the students understanding of different systems that are related to each other and how it impacts their design. For instance, the student below analyzes the information provided in the memo and extrapolates the information on the size of the asteroid and its effect on climate into how it will affect food, water, and air which are the primary needs for humans to survive. The students showed evidence of this relational understanding while rationalizing their design choices.

Student: If it is that big (asteroid size), then the impact is going to big and it is going to create winter for a long time which will affect the produce... depending on how cold it gets the water might freeze and then all technology might be damaged…. We will have dust clouds and we need filtered air…

Theme Four: Collaboration

The fourth theme that emerged from the data analysis is the students understanding of the need for a team. All of the students when explicitly asked what would be their next step or through their process of rationalizing their design choices acknowledged that they will need a team of experts to work together to be a able to design and build the cavern.

Student: I am going to have some geologists, someone from NASA some good engineers who can build homes, I am of course going to need the government, and someone who can broadcast where you need to evacuate...

Overall, students possess a rudimentary understanding of angles, parallel lines, and engineering thinking. These findings framed the mathematical learning goals of the instructional sequence as students would justify that two lines are parallel by identifying, *that the length of all the perpendicular segments between them are same* and *that if those two lines are cut by a transversal, the corresponding angles are congruent and the two alternate interior/exterior angles are congruent and the two same-side interior/exterior angles are supplementary*. The instructional sequences were designed to elicit this understanding as the students engage in them.

Design of Engineering Problem Based Instructional Sequences

Gravemeijer and Doorman (1999) highlight the role of context problems as, "...context problems are intended for supporting a reinvention process that enables students to come to grips with formal mathematics" (p. 111). Combining this notion with the understanding of the students' concept images of angles and parallel lines and their engineering thinking which is rudimentary as revealed in the findings above, the instructional sequences of building parallel roads in a residential community and constructing 3D models of two-story homes was developed. The problems within the sequences were designed to capitalize on students' current conceptions of angles and parallel lines (as revealed in the interviews), yet utilizing contextual features to revise those conceptions. The instructional activities were designed to develop students' understanding of measuring angles as the degree of turn and parallel lines as the same distance apart.

Micro and Macro Learning Cycles of Instructional Sequences

Karplus and Thier (1967) introduced the learning cycle and it comprises three distinct phases: *exploration* - students explore through data collection via open or guided inquiry, *concept invention* - students analyze the data to identify patterns and are introduced to appropriate scientific terminology, and *application* - students apply the newly learnt concept into new setting to reinforce their understanding. Combining this notion of learning cycles with systems thinking approach to STEM integration as to use engineering problem to motivate mathematical thinking, the instructional sequences are structured into macro and micro learning cycles. In the macro learning cycle *exploration phase* includes the introduction of engineering problem; mathematical instructional sequences that are situated within the context of the engineering problem, and development of solution for the engineering problem.

In the macro learning cycle *concept invention phase* includes the build, test, and redesign of the solution to the engineering problem and the macro learning cycle *application phase* is proposing the final solution and applying the ideas to other scenarios. There are several mathematical instructional sequences in the macro exploration phase and each of those sequences comprises of a micro learning cycles with *exploration, concept invention and application phases* for the mathematical concept. Figure 6 represents these macro and micro cycles visually for better understanding. This framework will help the K-12 teachers visualize the role of the engineering and mathematics in their classrooms. It is important to note that this approach addresses the tension problem discussed with existing approaches to STEM integration by placing separate emphasis on engineering and mathematics depending on the goal of corresponding phase.

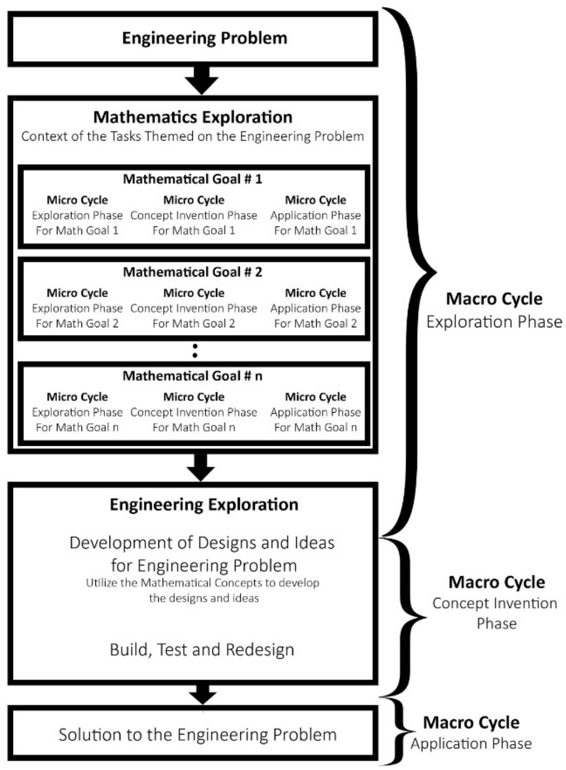

Figure 3. 6: Macro and Micro Learning Cycles of Instructional Sequences

Macro learning cycle exploration phase. Designing a residential community is the engineering problem used to provide context for the mathematical task where the students identified the design constraints from an architect’s brief. In essence, the students played the role of an architect and were asked to develop the Phase II of an existing residential community given a map of Phase I. One of the constraints was to build a road parallel to the existing road on Phase I for aesthetic reasons, the context for the first mathematical instructional sequence.

Micro learning cycle 1. The engineering problem motivated students to explore the properties of Parallel Lines, a mathematical concept to design their parallel roads. Student groups explored the possibility of using pre-drawn, existing parallel roads in Phase I and measuring the distance between the two existing roads to create new parallel roads (*Exploration*). This led to the discussion of the concept of equidistance in parallel lines, which was the learning goal of this cycle (*Concept Invention*). The students then verbalized their understanding by composing an email to explain the process to their architect colleague who is designing parallel roads for another project (*Application*).

Micro learning cycle 2. The student groups then were challenged that in real world, it is difficult to find equidistant points to draw the parallel road through the forested area. So students groups explored the possibility of using angles at the intersection of the parallel roads in Phase I and using the same angles to create the new parallel roads for Phase II (*Exploration*). This led to the discussion of the properties on parallel lines based on the angles such as corresponding angles are congruent and so on (*Concept Invention*). The students then verbalized their understanding by rewriting the email to explain the new process to their architect colleague working on another project (*Application*).

Students then explored decontextualized textbook problems to extend their understanding of equidistant and angle relationships of parallel lines to problems that similar to the ones on standardized assessments. Students were introduced the different terminologies specifically corresponding, alternate interior/exterior, and same side interior/exterior angles and the relationship between them. The application phase of the above to micro cycles are still within the same context but a different situation and hence, a horizontal application of the mathematical concept. In order to achieve a vertical application, the students explored tiling the road with pre-built triangular modular blocks. The goal was to see if the students are able to extend their understanding of parallel lines and view the opposite lines in the geometric shapes that are created by the tiled modular blocks are parallel.

Macro learning cycle concept invention phase. Student groups explored the rest of the design constraints and addressed each of them to create their first draft of their design of the residential community. The idea is to allow students to design and develop the rest of the residential community roads using the principles of parallel lines they explored in earlier cycles. Student groups used a scaled version of the map of the area they were developing and they proportionately calculated the dimensions of the lots of land per home, amenities and the roads in the community.

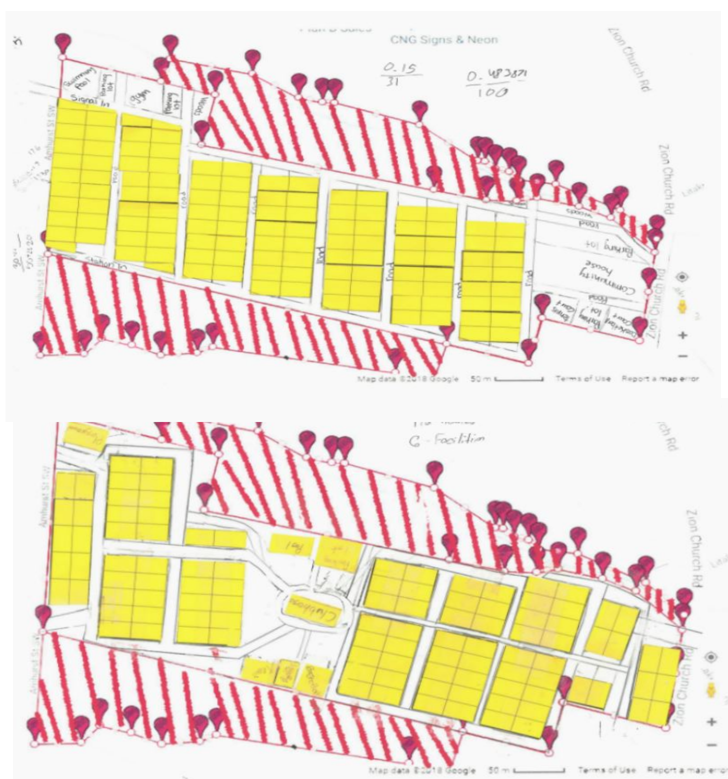

Figure 3. 7: Sample Student Designs of the Residential Community

Macro learning cycle application phase. The classroom teacher acting as the client or the developer that hired the architects (students) then evaluated the first draft of the residential community design. Student groups revised their design and presented it to the whole classroom (Figure 7). It is important to note that all of the instructional sequences are situated within a real-world situation and the student groups engaged in contextual problems that are not contrived. It made the whole learning experience holistic, an outcome of viewing engineering and mathematics integration from a systems thinking perspective.

Post-Interview Analysis

A post-interview was conducted to study if the engineering based instructional sequence, which was designed based on the pre-interview questionnaire analysis helped the students improve their understanding of the mathematical concepts related to angles and parallel lines. Post-interview analysis revealed that there was an overall improvement in conceptual understanding of angles and parallel lines among the four students. The discussion below addresses how each of the themes that emerged from pre-interview analysis have evolved in the post-interview after the students engaged in the engineering based mathematical instructional sequences. The three themes of angle are as follows,

Theme One: Using Prototypes or Reference Images

Majority of the students still use reference images and angles. In figure 8, student identified the 90° similar to the pre-interview but he/she was also able to split the 90° into two 45° and also the outer angle (270° angle). This rationale shows that the student has a better understanding of what the number 90° is made up of and its relationship to other angles in the figure.

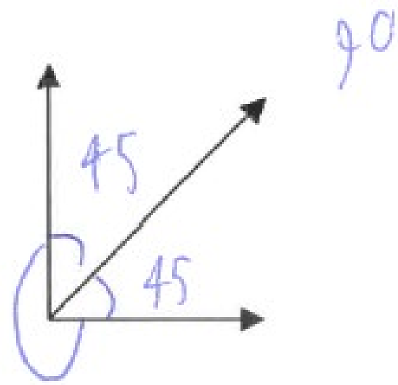

Figure 3. 8: Prototype or Reference Images

Theme Two: Angles as Corners

Now, students view angle as the distance between two or more intersecting lines. For instance, the student below defined angle as "*the distance between the shortest part of the lines*" and on probing rationalized his definition by saying it is important to measure at the shortest portion of the intersecting lines. Students still tend to view angles as distance apart between lines as opposed to the amount or degree of turn between the intersecting lines.

Interviewer: So when you say it (angle) is the distance between two lines and you have marked it here (points to the curve drawn by the student near the point of intersection). But that distance is different from this distance (points to the farthest from the point of intersection. So how does that work?

Student: Yes, that is why you have to measure only at the shortest part.

Theme Three: Decoupling versus Decomposing

Students were no longer dissociating the original angle from the two new angles when the original angle is split into two by a new ray. The student makes the rationale for estimating the new split angles to be 45^0 each because the total of the two is 45^0 which is the original angle.

Interviewer: Can you make an estimate of those two angles?

Student: 35... this is 90 (points to the original angle) so it will be 35 and 35 (split angles). No that will make it only 70 (original angle). I think it will be 45 and 45 (split angles) and it will make it 90. That makes sense.

The two themes of the parallelism are as follows,

Theme One: Never Touch

Students still view parallel lines as two lines that never touch and when probed further they rationalize it by the equidistant property of the parallel lines.They tend to use the never touch or equidistant rule if it is just two lines and use angles relationship if there is an intersecting line. They never use an imaginary intersecting line to explain parallelism. In figure Q below, the students argued for parallelism using the angle relationship of parallel lines.

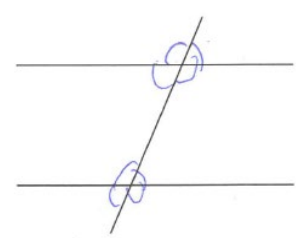

Figure 3. 9: Angle Relationship of Parallel Lines

Theme Two: Same Shape Pattern

The arguments used to discuss parallelism based on the patterns of lines/curves is not as widely used as in the pre-interview. Majority of the students tend to use equidistant rule and with angles relationship wherever appropriate. The student below (Figure 10) uses the equidistant rule to explain parallelism between a line and curve as opposed to using same shape pattern argument.

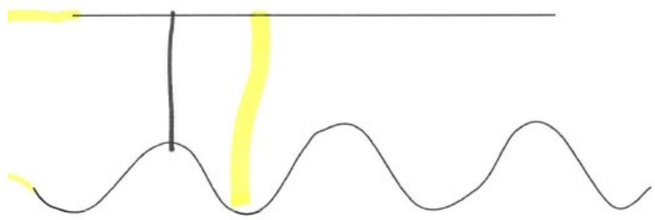

Figure 3. 10: Parallelism in Lines and Curves

Students showed an improved understanding of the four themes of the engineering thinking namely *Design Process, Ethical Considerations, Relational Design, and Collaboration*. For the post interview students engaged in an engineering design problem where they design a plant growth chamber for a lunar outpost station. One of the major difference was the greatly improved student's understanding of engineering design process who was identified as the lowest performer by the classroom teacher. Since, it is a STEM school the students are exposed to the simple engineering design process that is *Ask, Imagine, Plan, Create, and Improve*. It is evident that by engaging in engineering and mathematics integrated instructional sequence with systems thinking approach, this low performing student demonstrated a sophisticated and detailed understanding of the engineering design process. Student laid out the next logical sequence of steps as planning which is identifying the constraints, research, experiment, building a prototype, testing, refining the design and building a final growth chamber (Figure 11). All of the students identified the need for a team of experts to contribute to the design of the lunar growth chamber (*Collaboration*). Students also demonstrated their relational understanding by identifying the plant needs air, water, sunlight and nutrients to be able to grow on earth from the prior science knowledge and applied it to their design by including appropriate ways of meeting those needs.

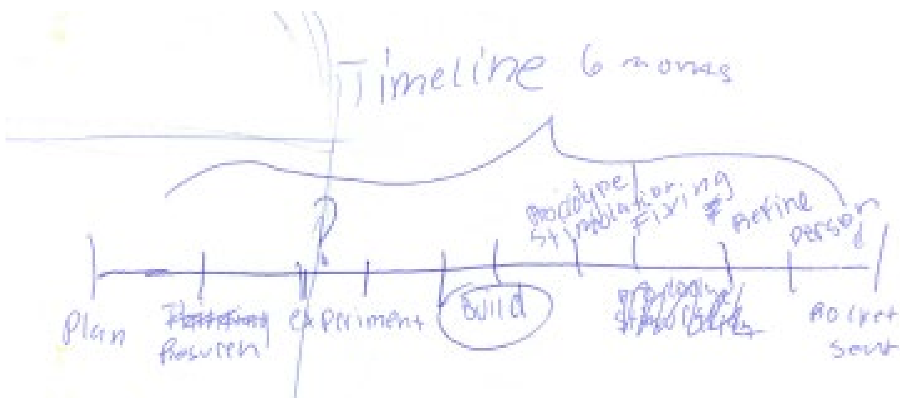

Figure 3. 11 Logical Sequence of Steps to Build the Plant Growth Chamber

Implications for Practice

Interdisciplinary approach to STEM is often criticized for its career-focused approach (Kelley & Knowels, 2016) and its theoretical implications as opposed to its practicality in the classroom. At a surface level, mathematics and sciences are applied in engineering to develop a technology; but a deeper understanding of the individual subjects is equally important. For single subject-area teachers, this may require cross-curricular collaboration to plan and implement a strong STEM lesson. Collaboration is not a new concept for many P-12 teachers. Teachers often meet regularly in professional learning communities (PLCs) to improve their classroom practice for their students. Collaborating to implement a STEM lesson may provide additional challenges, however.

If this lesson is being taught as part of students' core subject classes, those teachers will first be challenged with finding a common planning time to develop the context of the lesson (typically provided by the engineering and/or technology application and tied to mathematical and science standards of study). Then, teachers will need to collaborate to orchestrate the lesson within the given time constraints of the school schedule, switch back and forth between applied and theoretical learning in each of the various subjects (depending on students' needs), as well as analyze student's academic performance in each of the applied subjects. Such successful collaboration, although complex, leads to students having a shared investment in the endeavor (Blumenfeld, Krajcik, Marx, & Soloway, 1994).

The key to making this collaborative effort successful is cognizant intentionality. Teachers must remain focused on their purpose for contribution to the collaborative as well as intentional about the STEM lesson objective, including the content standards being taught. Furthermore, teachers need to remain aware of the balance between theoretical and applied aspects of the content they teach instead of focusing on one or the other. STEM based learning, at its heart, is an investigative process that allows the learner to dive deep into a topic and use mathematics and science as tools to create a solution. The STEM practices and principles lend opportunities for learning to be more student-centric than teacher-centric.

The content, regardless of the content discipline, is never separated from other disciplines, thereby making the construction and the application of knowledge easier (Fairweather, 2008). These ideas applied to STEM-based learning opportunities focus on the access to students' foundations of knowledge and ways of thinking that force them to engage as a community that collaborates on activities. This recommendation of teacher's to collaboratively work together also aligns well with the systems thinking approach wherein the different classrooms are the subsystems and the teachers who are experts in their discipline come together to work synergistically and create an learning environment that is beneficial for both the learners and the instructors.

Conclusion

Current in-service mathematics teachers are asked to design and teach in STEM integrated classrooms, yet most of them are not academically trained in engineering and technology. This study is part of a larger investigation focused on a research-based framework for STEM integration. The analysis of student thinking relative to angles, parallel lines, and engineering thinking is important to this study as a foundation for informing the larger design research process. The analysis of student thinking revealed several limitations in students' current conceptualization of angles and parallel lines, both of which are critical components in the target instructional tasks embedded within the engineering context of planning the roads and houses in a community. The students' current perspectives with limited understanding of angles and parallel lines inform the larger design research study by setting up instructional tasks that specifically address these issues. This study underscores the role of visiting and revisiting student thinking as a necessary step in the design research process.

References

Aronson, D. (1996). Overview of systems thinking. *Retrieved January*, *8*(2009), 518-560.

Betts, F. (1992). How systems thinking applies to education. *Educational Leadership*, *50*(3), 38-41.

Blumenfeld, P. C., Krajcik, J. S., Marx, R. W., & Soloway, E. (1994). Lessons learned: How collaboration helped middle grade science teachers learn project-based instruction. *The Elementary School Journal*, *94*, 539–551.

Brown, J. (2012). The current status of STEM education research. *Journal of STEM Education: Innovations and Research*, *13*(5), 7.

Bybee, R. W. (2010). What is STEM education?. *Science*, *329*(5995), 996-996.

Capraro, M. M., & Jones, M. (2013). Interdisciplinary STEM project-based learning. In R. M. Capraro, M. M. Capraro, & J. R. Morgan (Eds), *STEM Project-Based Learning* (pp. 51-58). Rotterdam: Sense Publishers.

contestation across cultures. New York: Rowman and Littlefield.

Czerniak, C. M., Weber Jr, W. B., Sandmann, A., & Ahern, J. (1999). A literature review of science and mathematics integration. *School Science and Mathematics*, *99*(8), 421-430.

Fairweather, J. (2008). Linking evidence and promising practices in science, technology, engineering, and mathematics (STEM) undergraduate education. *Board of Science Education, National Research Council, The National Academies, Washington, DC*.

Fyhn, A. B. (2008). A climbing class' reinvention of angles. *Educational Studies in Mathematics*, *67*(1), 19-35.

Glaser, B. & Strauss, A. (1967). Grounded theory: The discovery of grounded theory." *Sociology The Journal Of The British Sociological Association, 12*, 27-49.

Gravemeijer, K., & Doorman, M. (1999). Context problems in realistic mathematics education: A calculus course as an example. *Educational studies in mathematics*, *39*(1-3), 111-129.

Happs, J. C., & Mansfield, H. (1989). Students' and Teachers' Perceptions of the Cognitive and Affective Outcomes of Some Lessons in Geometry. *Proceedings of Annual Meeting of the American Educational Research Association* (pp. 1–35). San Francisco, CA.

Henriksen, D. (2014). Full STEAM ahead: Creativity in excellent STEM teaching practices. *The STEAM Journal, 1*(2). Retrieved from http://scholarship.claremont.edu/steam/vol1/iss2/15

Hurley, M. M. (2001). Reviewing integrated science and mathematics: The search for evidence and definitions from new perspectives. *School science and mathematics*, *101*(5), 259-268.

Israel, M., Maynard, K., & Williamson, P. (2013). Promoting literacy-embedded, authentic STEM instruction for students with disabilities and other struggling learners. *Teaching Exceptional Children*, *45*(4), 18-25.

Karplus, R., & Thier, H. D. (1967). *A new look at elementary school science: Science curriculum improvement study*. Rand McNally.

Keiser, J. M. (2004). Struggles with developing the concept of angle: Comparing sixth-grade students' discourse to the history of the angle concept. *Mathematical Thinking and Learning*, *6*(3), 285-306.

Keiser, J. M., Klee, A., & Fitch, K. (2003). An assessment of students' understanding of angle. *Mathematics Teaching in the Middle School*, *9*(2), 116.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 1–11.

Kim, D. H., & Law, H. (2012). Gender gap in maths test scores in south korea and hong kong: role of family background and single-sex schooling. *International Journal of Educational Development, 32(*1), 92–103.

Kuenzi, J. J. (2008). *Science, technology, engineering, and mathematics (STEM) education: Background, federal policy, and legislative action*. Retrieved from Congressional Research Service Reports website: http://digitalcommons.unl.edu/crsdocs/35

Mahoney, M. P. (2010). Students' Attitudes toward STEM: Development of an Instrument for High School STEM-Based Programs. *Journal of Technology Studies*, *36*(1), 24-34.

Meyrick, K. M. (2012). How STEM education improves student learning. *Meridian*, *14*(1).

Mitchell, P. (2005). What's in a name? Multidisciplinary, interdisciplinary, and transdisciplinary. *Journal of Professional Nursing, 21*(6), 332–334. doi:10.1016/j.profnurs.2005.10.009

National Council for the Social Studies. (n.d.). Social studies: The original STEM. Retrieved from https://www.socialstudies.org/getting-social/social-studies-original-stem

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common Core State Standards for Mathematics.* Washington, DC: Authors.

National Research Council. (2013). *Next generation science standards: For states, by states*.

National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.

Pang, J., & Good, R. (2000). A review of the integration of science and mathematics: Implications for further research. *School Science and Mathematics, 100(2)*, 73-82.

Park, J. Y., & Son, J. B. (2010). Transitioning toward transdisciplinary learning in a multidisciplinary environment. *International Journal of Pedagogies and Learning, 6*(1), 82-93.

Plomp, T., & Nieveen, N. (Eds.) (2007). An introduction to educational design research. *Enschede, the Netherlands: SLO*

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

Richmond, B. (1994). System dynamics/systems thinking: Let's just get on with it. In *International systems dynamics conference, Sterling, Scotland*.

Seymour, S. J., & Luman, R. R. (2011). Academic perspectives of systems engineering. *Johns Hopkins APL Technical Digest*, *29*(4), 377-386.

Stephan, M. L. (2015). Conducting classroom design research with teachers. *ZDM*, *47*(6), 905–917.

Stephan, M., Pugalee, D., Cline, C., & Cline, J. (2016). *Lesson imaging in math and science: Anticipating student ideas and questions for deeper STEM learning.* ASCD.

Stromquist, N. P., & Monkman, K. (2014). *Globalization and education: Integration and*

Tall, D., & Vinner, S. (1981). Concept image and concept definition in mathematics with particular reference to limits and continuity. *Educational studies in mathematics*, *12*(2), 151–169.

Von Bertalanffy, L. (1968). General system theory. *New York*, *41973*(1968), 40.

Wang, H.-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM Integration: Teacher perceptions and practice STEM integration: Teacher perceptions and practice. J*ournal of Pre-College Engineering Education Research (J-PEER)*, *1*(*2*), 1–13.

Wilhelm, J. (2014). Project-based instruction with future STEM educators: An interdisciplinary approach. *Journal of College Science Teaching, 43*(4), 80-90.

Zollman, A. (2012). Learning for STEM literacy: STEM literacy for learning. *School Science and Mathematics*, *112*(1), 12-19.

CHAPTER 4 [ARTICLE 3]: STEM INTEGRATION FROM A SYSTEMS THINKING PERSPECTIVE: ENGINEERING AND MATHEMATICAL PRACTICES

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Introduction

Science, Technology, Engineering, and Mathematics (STEM) education, as it is known today, has a relatively young history in the United States. Albeit young, STEM is one of the fastest growing educational disciplines due to global headlines that paint a world economy that relies heavily on advancements in science and technology. Seymour and Luman (2011) highlight the importance of introducing secondary students to the ideas of STEM and possible careers in the field for a strong STEM educational pipeline, they believe, is critical in preparing sufficient numbers of qualified individuals for future engineering and technology careers. While there has been a nationwide push to increase STEM in secondary schools, the debate regarding the best practices for integrating STEM across multiple subjects still exists (Stephan, Pugalee, Cline, & Cline, 2016).

One of the greatest challenges facing secondary STEM teachers today is effectively integrating STEM content into their core classes. Many barriers to seamless integration currently exist, such as the static curricular requirements set by grade-level standards, rigid time blocks of instruction, and a general lack of STEM resources and materials. Instructional theories related to interdisciplinary practices have been pursued in the past, yet many of these barriers remain as a current threat to creating holistic STEM learning experiences for today’s learners. STEM education started as a way of providing additional rigor and depth for gifted students, but over the years, it has proven effective with a range of students and, in fact, has improved disadvantaged students' motivation and performance.

The purpose of this paper is to contribute to a larger research that posits the benefits of envisioning STEM education through the pragmatic theoretical lens of Systems Thinking going forward. Recent educational standards reforms such as Next Generation Science Standards (NGSS) and Common Core State Standards for Mathematics (CCSSM) encourage integration of engineering and technology in science and mathematics classrooms. NGSS has explicit language on integration in its Science and Engineering practices but CCSSM does not provide the same. It beckons the need to explore the practices that emerge from a classroom when student engage in instructional sequences that are purposely and intentionally designed from a systems thinking perspective.

This design research study was conducted in a 7th grade mathematics classroom of a STEM middle school in a suburban school district in the southeast region of United States. The exploration of student's understanding of angles, parallel lines, and their engineering thinking combined with perspectives from the literature was utilized to design the context of the engineering based instructional sequence of building parallel roads in a residential community and constructing 3D models of two-story homes. This research is comprised of a pre-interview to assess the existing conceptions of angles and parallel lines and their engineering thinking, design and implementation of engineering-based instructional sequences, and a post-interview to assess the changes in conceptions of angles and parallel lines and their engineering thinking. The following research questions guided this study,

1. What are the classroom STEM practices that emerge as students engage with the instructional sequences and sequence designed based on the STEM integration conceptual framework?
2. How did the instructional sequences and its implementation enable and constrain the emergence of STEM practices in the middle grade mathematics classroom?

STEM Integration: A Systems Thinking Perspective

STEM education is at its early stages of development and the two common approaches include using engineering as a pedagogical tool where engineering and technology applications are used to learn science and mathematics, and engineering as a stand-alone subject where students use their science and mathematics knowledge and skills to learn engineering. Irrespective of the approach, integration of STEM in regular K-12 classrooms has been the primary driving factor for reformations in the curricula, standards and policies concerning STEM education.

The National Research Council (2014) report titled, *STEM integration in K-12 education: Status, prospects, and an agenda for research* highlights the notion that STEM integration is not teaching the individual subjects Science, Technology, Engineering and Mathematics that make up the acronym nor attempting to matching the essential standards among these subjects with the pretext of highlighting the connections between these subjects. Meaningful STEM integration should be guided by the fundamental idea of systems thinking that is moving away from establishing static relationships and situate learning within a context for the learners.

In other words, standards need to take a step back in the design of STEM based lesson because the combination of standards across the four individual subjects is unique to that lesson. The central structure across STEM lessons might more effectively build on relationships by focusing on STEM practices that include the engineering design process, design thinking, systems thinking, logical thinking, problem solving and so on. The purpose of this re-conceptualized thinking towards STEM integration is to show the naturally existing relationships between the individual subjects Science, Technology, Engineering and Mathematics.

The intricacies of today's technologically advanced world enforce the view that the future workforce, that is the present day students, must be outfitted with a new set of core skills and knowledge including skills and ways of thinking that involve problem solving, gathering data, evaluating evidence, making sense of information and communicating findings with others. Science, Technology, Engineering, and Mathematics (STEM) education provides students with opportunities to develop such skills and knowledge and also what to do with that knowledge (Mahoney, 2010) but only if we develop approaches that move away from surface level thinking about content integration that is limited in developing ways of thinking.

STEM Literacy

This approach also builds what is often referred to as "STEM literacy" (Zollman, 2012), which is the last missing puzzle in the above discussion on systems thinking approach to STEM teaching and learning. The notion is that the overall aim of such integrated approaches to learning is prepare students to be STEM literate (Israel, Maynard, & Williamson, 2013) that is to consume, analyze and apply the relevant information presented to them mainly in their professional life but also in their personal life. There is no question that technological advances around us have grown rapidly and it is important that students are not just passive users but active users that constantly think critically to improve that technology.

Zollman (2012) argues for moving from learning for STEM Literacy to STEM Literacy for learning by stating that

> ... to evolve from "learning to know and learning to do" to "learning to live together and learning to be" in STEM literacy... to view STEM literacy as a dynamic process, spotlighting the three strata in the STEM literacy process: educational objectives of the content areas; cognitive, affective, and psychomotor domains from learning theory; and economic, societal, and personal needs of humanity (p.18).

Stephan, Pugalee, Cline, and Cline (2016) use the UNESCO's four pillars of learning: learning to *know*, *do*, *live together*, and *be* to characterize STEM literacy. They acknowledge the dynamic nature of STEM literacy through these four pillars, which underscore the inherent nature of systems thinking in effective STEM teaching and learning. Extending the original systems argument for STEM integration, literacy in individual subjects does not mean STEM literacy overall. Expertise in individual subject literacy will inform the STEM literacy but there can be certain unique opportunities and challenges, which needs further exploration.

Standards of Practice

STEM education is a key factor in preparing students that are trained with practical and hands-on skill set to work in highly demanding jobs. It started, as a way of providing the additional rigor and depth of gifted students' teaching and learning but over the years it has proven as effective with average students and has in fact improved disadvantaged students motivation and performance (Kim & Law, 2012). Opportunities for improving nation's innovation capacity and in turn increased employment opportunities have been the core reasons for several influential educational policies to be put into practice (NRC, 2014).

It should be no surprise that there is a huge push for reformation of educational standards by organizations such as National Council of Teachers of Mathematics, the American Association for the Advancement of Science, the National Research Council, and the International Technology Education Association. Recent educational standards reforms such as Next Generation Science Standards (NGSS) and Common Core State Standards for Mathematics (CCSSM) encourage integration of engineering and technology in science and mathematics classrooms (Kuenzi, 2008).

For instance, the eight practices of science and engineering identified by NGSS are listed in the Table 1.

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information (NRC, 2013)

Interestingly, such a specific language of engineering or technology is used in the Practices of the Common Core State Standards for Mathematics (Refer to table 1). In spite of the obvious connections between mathematics and engineering, this relationship may not be obvious for a mathematics teacher who is not trained in the field of engineering. Then it becomes a necessity to make these connections obvious. Teachers need opportunities to develop the skills and knowledge required in solving a problem with perspectives from both engineering and mathematics.

Table 4. 1: Engineering Practices and Common Core Standards of Mathematical Practice

Engineering Practices **Kelley and Knowles (2016)**	**Common Core Standards of Mathematical Practice**
Begins with a problem, need, or desire that leads to an engineered solution.	Make sense of problems and persevere in solving them
Engineering investigation to obtain data necessary for identifying criteria and constraints and to test design ideas.	Use appropriate tools strategically
Using models and simulations to analyze existing solutions.	Model with mathematics
Analyzing and interpreting data collected from tests of designs and investigations to locate optimal design solutions.	Reason abstractly and quantitatively
Mathematical and computational thinking are integral to design by allowing engineers to run tests and mathematical models to assess the performance of a design solution before prototyping.	Attend to precision
Constructing designing solutions using a systematic approach to solving engineering problems based upon scientific knowledge and models of the material world. Designed solutions are optimized by balancing constraints and criteria of existing conditions.	Look for and express regularity in repeated reasoning. Look for and make use of structure
Arguments with evidence is key to engineering for locating the best possible solutions to a problem. The location of the best solution is based on a systematic approach to comparing alternatives, formulating evidence from tests, and revising design solutions.	Construct viable arguments and critique the reasoning of others

Kelley and Knowles (2016) highlight the similarities and differences between engineering and technology practices and skills to science practices and skills. However, their comparisons lack an explicit comparison between mathematical practices to science, engineering and technology skills and practices. The core of Engineering and Technology practices is aimed at figuring out the best solution to a problem under the given conditions and follows a process of identifying the parameters and systematically solving the problem which is typical of both science and mathematics standards of practice.

Table 1 shows the similarities and differences between the common core state standards of mathematical practice and engineering practices and the same can be extended to scientific practices as well. A quick look at the table will show the similarities predominantly but the fundamental difference between the two is that pure mathematics strives to find an accurate solution whereas engineering looks for the best solution within the given conditions of a problem. Therefore, the crucial standard of practice is constructing a argument to justify that a solution is the best among the possible and hence the need for literacy in the STEM integration model.

Methodology

This research paper will focus on the emergence of classroom engineering and mathematics practices as the 7th grade students engage in the engineering-based instructional sequences of building parallel roads in a residential community and constructing 3D models of two-story homes. The research reported in this paper aims to capture the engineering and mathematical practice that emerge from the classroom for K-12 teachers and instructional designers to incorporate in their STEM integrated classrooms and also for instructional designers to include components that evoke these practices in their design of instruction. The research was conducted in a 7th grade mathematics classroom of a STEM middle school in a suburban school district in the southeast region of United States.

The classroom teacher was part of the design team along with faculty specializing in mathematics education, chemistry, and engineering at a large urban university and a mathematics education faculty member from an international university. The larger research study included a pre- and post-interview of four students from the classroom, design and development of instructional sequences by the design team, classroom implementation, and teacher reflection. This article focuses on the analysis of video recording of classroom implementation of both overall class and the small group works, daily and overall reflection interview of the classroom teacher to identify the practices that emerge in the classroom. During the implementation of the STEM instructional sequences, the small student groups' work and the overall lesson were video/audio recorded.

After each of the implementation, the teacher and the researcher met to reflect on that day's implementation. Researcher also conducted an interview with the teacher about specific instances that occurred in the classroom and the specific interview protocol was designed accordingly during implementation. These reflections and interview were aimed to inform further implementations and as data of the progression of the phases for later analysis on emergence of STEM practices. Small student groups presented their designs at the end and were interviewed about their design rationales. The interview protocols was designed accordingly during implementation as well. All of the interviews were audio/video recorded.

Data Analysis

Video recording of classroom implementation was the major source of data which was analyzed using Toulmin's model of argumentation to capture the STEM practices that emerge when students engage in designed STEM instructional sequences. Toulmin's model of argumentation provides structure and function of certain parts of an argument and the core of an argument includes three parts: *data*, *claim* and *warrant* (Toulmin, 1969). In order to make an argument, one has to make a *claim* and support the claim with appropriate *data* or evidence. *Warrant* is providing more clarification to connect the data and claim when the relationship between data and claim is challenged and *backings* are provided to validate the argument when warrant remains implicit (Rasmussen and Stephan, 2008).

After identifying the arguments, researchers utilized constant comparative method by Glaser and Strauss (1967) to analyze them. In this method, multiple researchers separately analyze all the arguments by letting themes emerge during ongoing data analysis. A researcher starts with, say, arguments from one class session and attempts to find any common themes as he/she reads across all the arguments. Once a theme emerges, he/she continues data analysis to either support or refute the theme. At the completion of all data analysis, several data-generated themes emerged and were triangulated with the other researchers to verify or throw out proposed themes. Documents such as student worksheets, rubrics, engineers' log and design solutions were used to triangulate the findings.

STEM Instructional Sequences

The pre-interview questionnaire on student conception of angles, parallel lines and engineering thinking revealed that they possess a rudimentary understanding of angles, parallel lines, and engineering thinking. These findings framed the mathematical learning goals of the instructional sequence as follows,

- Students would justify that two lines are parallel by identifying that the length of all the perpendicular segments between them are same.
- Students would justify that two lines are parallel by identifying that if those two lines are cut by a transversal, the corresponding angles are congruent, the two alternate interior/exterior angles are congruent, and the two same-side interior/exterior angles are supplementary.

The goal of the instructional sequences is to capitalize on the students existing conceptions of angles and parallel lines and use the contextual features of the engineering problem to revise them. Students were introduced to the engineering problem of designing a residential community and play the role of an architect. They were given a client brief with all the specifications and one of the design constraints is to design a road parallel to an existing road. This motivated the students to think about and explore the concept of parallelism. Students engaged in two instructional sequences that were situated within the context of designing the residential community and explored the notions of equidistant and angle relationship properties of parallelism as guided by the learning goals.

Students then completed their design of their residential community based on the design constraints and the angles and parallel concepts they explored earlier. They presented their solution to the classroom teacher who acted as the client and provided feedback. Student groups finalized their designs based on the feedback and presented their design rationale for the whole classroom. Design team was purposeful and intentional in the design of instructional sequences by using the engineering problem to motivate mathematical thinking. The instructional sequences were situated within the notions of systems thinking while integrating engineering and mathematics. The practices that emerge from such a classroom are classified as meta-practices. Because these practices are unique and emerge because of the synergistic relationship between engineering and mathematics as they are integrated holistically.

Meta-Practices

The manuscript explores the emergence of the following meta-practices at the classroom and the individual levels when the designed instructional sequence was used, (a) developing conceptual understanding in multiple subject areas; (b) building relationships among subject areas; (c) shifting back and forth between goals of the individual subject experts; (d) developing ethical thinking; and (e) rethinking communication.

Developing Conceptual Understanding in Multiple Subject Areas

The first meta-practice that emerged from the classroom was the idea of providing opportunities for students that allow them to utilize their conceptually understand from different disciplines. The design team did not intentionally design this meta-practice into the instructional sequences but it emerged. In both the overall and small group discussions, the students engaged in discussions that highlighted their conceptual understanding of the different disciplines. In the transcript below, a small student group is discussing why they should not be designing to build in the swamp.

The students argues that they cannot built in the swamp because of the stagnant water in the swamps when it rains and the presence of wildlife in the protected area. They are bringing in arguments based on their prior knowledge they obtained in their science classroom into their discussion to rationalize a design choice. Another instance of discipline that was not a part of the instructional sequences but emerged in the whole classroom discussion was on the use of Geographical Information Systems (GIS) data to be able to calculate the distance between two roads.

The students were aware of the purpose of the GIS technology from their social studies classroom and knew when and how to use it to solve the engineering problem. Even though the inclusion of ideas from other disciplines such as science, social studies or technology was not originally intended, they emerged in the classroom showing that the students tend to use their existing funds of knowledge from other disciplines in their arguments. It is important to note that these conceptual understandings from other disciplines are rudimentary in nature, as the students do not have the time or opportunity to explore them further.

Student 1: Do not put a home lot in the swamp area! (To student 2)

Student 2: Why?

Student 3: It is marked off in red so we cannot build there

Student 1: Also swamp will have water standing in it when it rains and there might be animals living in the area. So we cannot build there.

Student 4: The soil will be too wet to build too

Building Relationships among Subject Areas

The second meta-practice that emerged from the classroom was the idea of providing opportunities for students that allow them to view the synergistic relationship between the subject areas. This meta-practice was purposefully designed into the instructional sequences by the design team. In both the overall and small group discussions, the students engaged in discussions that highlighted their understanding of the synergistic relationship between the subject areas. The students went back and forth between the two subject areas depending on the goal they were focusing on currently.

In the transcript below, the teacher and the students engaged in a whole class discussion to develop a taken-as-shared (Yackel and Cobb, 1996) understanding of the concept of parallel lines. The discussion started with using distance between the two lines as the property to explain parallelism and then defaulted back to lines never touch each other (a rudimentary understanding). Then through probing based on the engineering context that you cannot use the parallel edge of the ruler to draw a parallel road in the real world, their conceptual understanding moved to a more sophisticated notion that the two lines are parallel if they are equidistant from each other.

The whole classroom moved back and forth from the engineering context to mathematical context or in other words, they mathematized the context to solve a problem and demathematized the solution back into the context. The engineering problem of needing to draw a parallel road motivated them to determine what it mathematically means to be parallel. This allowed them to understand the synergistic relationship between the two-subject areas mathematics and engineering.

Teacher: One of you two, explain to us what you did here? (points to the board with the diagram of roads where a new parallel road needs to be added)

Student 1: So the first row of houses is about an inch wide and it includes two rows of home. So the new road must also include two rows of homes and so it must be an inch away as well

Teacher: How do you know that is the exact placement of the line? Did you use a ruler?

Student 2: If you keep going with your finger across and the lines intersect eventually then they are not parallel.

Teacher: Ok. How can you mathematically convince me, that they are parallel or not parallel? Remember in the real world I do not have a big ruler to use its parallel edge to draw a parallel road.

Student 3: If you measure the distance between two points one on each line and if you keep measuring across the lines and if the distance remains the same then they are parallel

Student 1: ah! so distance between to the two lines remains the same across

Student 4: So I can measure different points from the original road at the same distance and if I connect all of them then the new new line or road must be parallel to the original road

Shifting Back and Forth between Goals of the Individual Subject Experts

The third meta-practice that emerged from the classroom was the idea of providing opportunities for students that allow them to view that the end goal of the each individual subject expert is different. This meta-practice was purposefully designed into the instructional sequences by the design team. In both the overall and small group discussions, the students engaged in discussions that highlighted their understanding that the goals of the individual subject expert is different from one another. This notion of difference in goals was heavily discussed in the design team meetings to ensure that while integration mathematics is not used as a tool to solve the engineering problem but the engineering problem is used to motivate students to think about the mathematical concept.

In the transcript below, the teacher is engaging the students in a whole class discussion on calculating the scaling factor for drawing the width of the road. One group uses the exact dimension provided in the brief as per the building code that is 29 feet for the width of the road and finds the scaled dimension to be 5.27mm. Another group uses the approximated 9m width as their dimension for their calculation and ends up with 5.4mm. If it was just mathematical calculations, the values are so close and both would be considered correct. However, in real world as the teacher points out when building the roads, that small difference can add up and result in an error at the end. The context of the problem drives the precision of the result.

In other words, since the students are playing the role of an architect designing the residential community, they are forced to be precise in their calculations, as it would lead to misalignments in the real world at the end. Students are motivated to think about which role they are playing and what the end goal of the role is. As an architect they need to be precise in their calculations but as a mathematician approximate solutions are acceptable.

The idea is that this discussion on the end goals of each discipline experts emerged from a purposefully and intentionally integrated classroom.

Teacher: Can you share the scaling calculations that your group calculated for the width of the road?

Student 1: We looked at the bottom of the paper and it shows a 50m scaled line and I measured it to be 30mm. So 50m in real life is represented by 30mm. The width of the road in real life is 9m. We divided 30mm over 50m and multiplied it by 9m and the scaled width is 5.4mm

Student 2: We used the width of the road as 29ft in real life and we converted 50m to 164.04ft. Then we divided 30mm by 164.94ft and multiplied it by 29ft to give 5.27mm.

Teacher: 5.4mm is different from 5.27mm. Which group is correct and why?

Student 3: Our group (5.4mm group) is correct

Teacher: Why?

Student 2: No. It says here (points to the client brief) that the width of the road is 29 feet, which is approximately 9m. We used the exact measurement. So we are correct

Teacher: Interesting. What do you think about that? (looks at 5.4mm group)

Student 1: The values (5.4 and 5.27) are almost the same

Teacher: Yes but since there will be so many roads in the community. The difference will add up and there will be an error at the end. Does that make sense?

Developing Ethical Thinking

The fourth meta-practice that emerged from the classroom was the idea of providing opportunities for students that allow them to think ethically while making design decisions. The design team did not intentionally design this meta-practice into the instructional sequences but it emerged. In both the overall and small group discussions, the students engaged in discussions that highlighted their ethical thinking while making design decisions or in other words being conscious of the impact of their decisions on social and environmental factors. The goal is to develop a sense of accounting for the needs and concerns of the larger global society in the students thinking or in other words using their content knowledge and skill to be aware of its real-world implications.

Student 1: These are our two rows of homes and the parallel road (points to the first row of homes the group added). After that we kept adding more rows of home and roads

Student 2: We decided to put our swimming pool and tennis court in the middle so it can be easily accessed by everyone.

Student 3: I like how you did the club house in the middle

Teacher: Why do you like it?

Student 3: It just looks nice and I can walk to it if I want or drive if I cannot walk

The transcript above is from the presentation a student group was making for the client/classroom teacher and the argument they used to justify their design choice of placing the amenities in the middle of the community (Figure 1) was that it will be easily accessible for all the house lots as opposed to if it was at one corner, then some has to travel farther to access it. This sense of social and environmental factors in designing solutions was evident in the pre- and post-interview as well. Students are particularly interested in problems with context that address social justice issues.

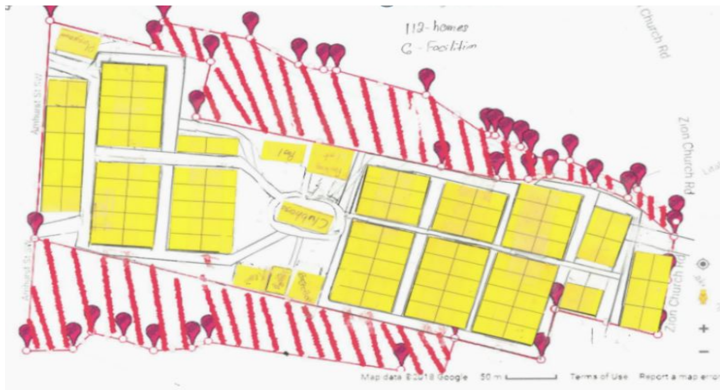


Figure 4. 1: Student Design with Amenities in the Center of Residential Community

Rethinking Communication

The fifth meta-practice that emerged from the classroom was the idea of providing opportunities for students that allow them to view that STEM experts must be able to communicate with different subject experts. The design team did not intentionally design this meta-practice into the instructional sequences but it emerged. In both the overall and small group discussions, the students engaged in discussions that highlighted their understanding for the need to rethink how they communicate depending on what is the current goal. The idea here is that each field is unique in its practices and goals and the same word can mean differently depending on the discipline. For instance, the word model can remind a mathematician of an equation while for an engineer it can remind of a physical model. Therefore, the STEM expert must be able to communicate between the disciplines and with non-technical personnel.

The transcript below is from student group's presentation of their final residential community design. The students were justifying their rationale for a certain design choices such as design parallel rows of home, increasing the lot size or using a key to identify the front and back of the lots. The idea here is that during the presentation, they are using mathematical concepts (parallelism) and it is real world implication (neatly organized row of homes). The real world implication is rudimentary but allows the students make those connections between the abstract concept and the real world. Students use of keys to identify the front and back of the house shows their thinking about communicating their design to both technical and non-technical audience.

Teacher: Can you tell us why you arranged your home lots they way you did?

Student 1: Because it looks organized

Teacher: What do you mean by that?

Student 2: We started with the first parallel road and kept everything parallel after that and so it looks neat

Student 3: I have a question, why is that lot at the end smaller than the rest?

Student 2: Which one?

Student 3: this one (points to the lot at the end of the row)

Student 1: That is not a seperate one. We will combine it with this (points to the one next to it) and make the lot bigger than the 0.15 acres

Teacher: Which is common in real world that some lots are bigger than the others and you have to pay more for those lots

Student 4: My grandmother is a real-estate agent and she tells the same and also you will also have marsh views. Also, the lots near the main road will drop the value because of the car noises

Teacher: What is the orange and green on the design?

Student 2: Oh that is the key to tell which is the front and back of the lot

Overall, the practices that emerged from the classroom are a result of synergistic interaction between mainly mathematics and engineering disciplines along with others. In this design research, this is the first cycle of implementation where certain emerged practices were intentionally designed into the instructional sequences and certain emerged by itself. The next step is to keep revising the instructional sequences until the emergence of practices stabilizes and no new practices emerge. This research focuses only on mathematics and engineering integration and opens up the possibility of focusing on the integration between other disciplines including science, technology, social studies, literacy, arts and so on.

Conclusion

Rather than focusing on a final product, which is a typical component of a project, a systems thinking approach encourages teachers to emphasize the multiple learning processes that are taking place in the classroom. One way teachers can do this is through a rubric that assess the intended skills and knowledge of that project as they emerge. Systems thinking approaches to STEM instruction have several implications for practitioners. Creating rubrics to use as assessments is one way teachers can embed systems thinking in their STEM instruction. Another way is to break the barriers of teaching these subjects in isolation from one another. In middle and secondary levels of education, subjects are commonly taught in separate blocks or class periods, which may stifle teachers' attempts to teach STEM subjects as interconnected disciplines.

Team-teaching or cross-curricular collaborative planning are two ways teachers can attempt to increase systems thinking in their lessons. The simple recognition of considering the individual subjects Science, Technology, Engineering and Mathematics as complex and treating them similarly remarkably changes the approach to STEM integration. With increased attention to assessment, STEM integration based on systems thinking theory places the process of learning at an equal importance to helping students score better end-of-grades. Traditional approaches would just connect the problem of needs of assessment to the solution of just standards-based curricula but taking a systems thinking approach considers other components of the educational system that contribute to the type of learning envisioned in STEM contexts.

References

Glaser, B. & Strauss, A. (1967). Grounded theory: The discovery of grounded theory." *Sociology The Journal Of The British Sociological Association, 12*, 27-49.

Israel, M., Maynard, K., & Williamson, P. (2013). Promoting literacy-embedded, authentic STEM instruction for students with disabilities and other struggling learners. *Teaching Exceptional Children*, *45*(4), 18-25.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 1–11.

Kim, D. H., & Law, H. (2012). Gender gap in maths test scores in south korea and hong kong: role of family background and single-sex schooling. *International Journal of Educational Development, 32(*1), 92–103.

Kuenzi, J. J. (2008). *Science, technology, engineering, and mathematics (STEM) education: Background, federal policy, and legislative action*. Retrieved from Congressional Research Service Reports website: http://digitalcommons.unl.edu/crsdocs/35

Mahoney, M. P. (2010). Students' Attitudes toward STEM: Development of an Instrument for High School STEM-Based Programs. *Journal of Technology Studies*, *36*(1), 24-34.

Meyrick, K. M. (2012). How STEM education improves student learning. *Meridian*, *14*(1).

National Research Council. (2013). *Next generation science standards: For states, by states*.

National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.

Rasmussen, C., & Stephan, M. (2008). 10 A Methodology for Documenting Collective Activity. *Handbook of design research methods in education: Innovations in science, technology, engineering, and mathematics learning and teaching*, 195.

Seymour, S. J., & Luman, R. R. (2011). Academic perspectives of systems engineering. *Johns Hopkins APL Technical Digest*, *29*(4), 377-386.

Stephan, M., Pugalee, D., Cline, C., & Cline, J. (2016). *Lesson imaging in math and science: Anticipating student ideas and questions for deeper STEM learning.* ASCD.

Toulmin, S. E. (1969). The uses of argument. Cambridge university press.

Yackel, E., & Cobb, P. (1996). Sociomathematical norms, argumentation, and autonomy in mathematics. *Journal for research in mathematics education*, 458-477.

Zollman, A. (2012). Learning for STEM literacy: STEM literacy for learning. *School Science and Mathematics*, *112*(1), 12-19.

CHAPTER 5: CONCLUSION

In essence, teaching and learning of the individual subjects that make the acronym STEM must move away from the compartmentalized approach towards an integrated approach of content domains. Secondly, given the natural similarities between engineering and mathematical practices there is a need for revised standards that consider common pedagogical practices that develop both principles and processes of reasoning. All the individual subjects should be given equal importance in a conceptual framework of genuine STEM integration which in-turn will drive a similar notion to classroom through corresponding pedagogical strategies.

The underlying intent of these STEM practices and principles is to train students to think like engineers/scientists and help students apply mathematics and sciences to the world around them (Brown, 2012). Teachers must be aware of their student's needs and interests when their pedagogical practices are informed by this re-conceptualized approach to STEM. With a systems-thinking approach, student-centric STEM based learning becomes not only a viable method of teaching, but possibly a highly effective method of learning as well.

Meyrick (2012) alludes to this idea by stating,

> STEM programs include powerful pedagogical practices centered on the student's active learning, including cross-curricular integration, project-based learning, authentic and alternative assessments, writing literacy via research and reflection, creating partnerships with the business community, and solving or attempting to solve authentic, real-world problems (para. 6).

In addition, recent advancements in technology have enabled humans to develop a new set of digital skills including enhanced visual and spatial skills and improved cognitive skills due to their interaction with video games, television and personal computers. With the increase in the number of resources available online, students have easy access to information in a shorter period of time (Prensky, 2001). Students develop the skills to acquire information on their own. Pedagogical strategies in traditional classroom environments must adapt to capitalize on this and engage students during their sessions of 50 to 90 minutes.

It is problematic at best to expect anyone, particularly students, to stay engaged for extended periods. Thus, teachers must implement pedagogical strategies to incorporate tangible resources and activities. It is important to note here that learning happens outside the classroom as well. In the worlds of mathematics and science, STEM-based learning allows students to use content and concepts as tools to solve problems. Thus, students must learn how to use the tools to engage in deep thinking to identify possible solutions and test their viability that is applying their knowledge and skills which is a higher order learning skill.

This process forces students to learn mathematics and science in ways that are different from static knowledge, as they are required to apply concepts and ideas in the formation of a solution or solutions to a problem situation. Classrooms must be conducive for students to collaborate with each other and engage with problem with a vested interest to find an appropriate solution. Finally, in order to ensure students are STEM literate requires rethinking our subject matter driven approaches and strategies to incorporate models that emphasize the underlying structures of the cognitive processes involved when one engages in true STEM learning. This can happen if systems thinking approaches drive research, policy and practices related to STEM education across P-12 and beyond.

REFERENCES

Albert, L. R. (2012). *Rhetorical ways of thinking: Vygotskian theory and mathematical learning*. New York, NY: Springer.

Bernstein, B. (2004). *The structuring of pedagogic discourse*. Routledge.

Berry, R. I., Bull, G., Browning, C., Thomas, C. D., Starkweather, K., & Aylor, J. H. (2010). Preliminary considerations regarding use of digital fabrication to incorporate engineering design principles in elementary mathematics education. *Contemporary Issues In Technology & Teacher Education*, 10(*2*), 167-172.

Blumer, H. (1969). Symbolic interactionism: Perspective and method. Englewood Cliffs, NJ: Petince Hall.

Brotman, J., & Moore, F. (2008). Girls and science: A review of four themes in the science education literature. *Journal of Research in Science Teaching*, 45(9), 971-1002.

Brown, J. (2012). The current status of STEM education research. *Journal of STEM Education: Innovations and Research*, *13*(5), 7.

Brown, S., Newman, C., Dearing-Smith, K., & Smith, S. (2014). Engineering encounters: Can a student really do what engineers do?. *Science and Children*, 51(*9*). 79.

Brush, T., & Saye, J. (2000). Implementation and evaluation of a student-centered learning unit: A case study. *Educational technology research and development*, *48*(3), 79-100.

Catsambis, S. (1995). Gender, race, ethnicity, and science education in the middle grades. *Journal of Research in Science Teaching*, 32, 243-257.

Clewell, B. C., & Braddock, J. H. (2000). Influences on minority participation in mathematics, science, and engineering. In G. Campbell, Jr, R. Denes, & C. Morrison (Eds.), *Access denied: race, ethnicity, and the scientific enterprise* (pp. 89-137). New York, NY: Oxford University Press.

Creghan, C., & Adair-Creghan, K. (2015). The positive impact of project-based learning on attendance of an economically disadvantaged student population : A multiyear study. *Interdisciplinary Journal of Problem-Based Learning*, *9* (2), 102-110. doi:10.7771/1541-5015.1496

Fantz, T. D., De Miranda, M. A., & Siller, T. J. (2011). Knowing what engineering and technology teachers need to know: An analysis of pre-service teachers engineering design problems. *International Journal of Technology & Design Education*, 21(*3*), 307-320.

Gallagher, J. M., & Reid, D. K. (2002). *The learning theory of Piaget and Inhelder*. Lincoln, NE: iUniverse.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American educational research journal*, *38*(4), 915-945.

Glaser, B. & Strauss, A. (1967). Grounded theory: The discovery of grounded theory." *Sociology The Journal Of The British Sociological Association, 12*, 27-49.

Hernandez, P. R., Bodin, R., Elliott, J. W., Ibrahim, B., Rambo-Hernandez, K. E., Chen, T. W., & de Miranda, M. A. (2014). Connecting the STEM dots: measuring the effect of an integrated engineering design intervention. I*nternational Journal of*

Technology and Design Education, 24(*1*), 107-120, 107–120. http://doi.org/10.1007/s10798-013- 9241-0

Huffman, D., Thomas, K., & Lawrenz, F. (2003). Relationship between professional development, teachers' instructional practices, and the achievement of students in science and mathematics. *School Science and Mathematics*, *103*(8), 378-387.

Karplus, R., & Thier, H. D. (1967). *A new look at elementary school science: Science curriculum improvement study*. Rand McNally.

Kimmel, H., Carpinelli, J., & Rockland, R. (2007). Bringing engineering into K-12 schools: A problem looking for solutions. *Proceedings of the International Conference on Engineering Education*, 1–5. Retrieved from http://icee2007.dei.uc.pt/proceedings/papers/49.pdf.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Mckenna, S. (2013). The dangers of student-centered learning–A caution about blind spots in the scholarship of teaching and learning. *International Journal for the Scholarship of Teaching and Learning*, *7*(2), 6.

Meyer, D. K., Turner, J. C., & Spencer, C. A. (1997). Challenge in a Mathematics Classroom : Students ' Motivation and Strategies in Project- Based Learning. *The Elementary School Journal*, 97(5), 501–521.

Meyrick, K. M. (2012). How STEM education improves student learning. *Meridian*, *14*(1).

Nanney, B. (2004). Student-centered learning. *Retrieved November*, *30*, 2012.

National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.

Plomp, T., & Nieveen, N. (Eds.) (2007). An introduction to educational design research. Enschede, the Netherlands: SLO.

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

Rasmussen, C., & Stephan, M. (2008). 10 A Methodology for Documenting Collective Activity. *Handbook of design research methods in education: Innovations in science, technology, engineering, and mathematics learning and teaching*, 195.

Reid, N., & Skryabina, E. A. (2003). Gender and Physics. *International Journal of Science Education*, 25 (4), 509-536.

Singer, J. E., Ross, J. M., & Jackson-Lee, Y. (2016). Professional Development for the Integration of Engineering in High School STEM Classrooms. *Journal of Pre-College Engineering Education Research (J-PEER)*, *6*(1), 3.

Tamim, S. R., & Grant, M. M. (2013). Definitions and uses: Case study of teachers implementing project-based learning. *Interdisciplinary Journal of Problem-Based Learning*, *7*(2), 71–101.

Toulmin, S. E. (1969). The uses of argument. Cambridge university press.

Vygotsky, L. S., & Rieber, R. W. (1997). *The collected works of LS Vygotsky: Problems of the theory and history of psychology* (Vol. 3). Springer Science & Business Media.

Wang, H.-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM Integration: Teacher perceptions and practice STEM integration: Teacher perceptions and practice. J*ournal of Pre-College Engineering Education Research (J-PEER)*, 1(*2*), 1–13. http://doi.org/10.5703/1288284314636

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining Computational Thinking for Mathematics and Science Classrooms. *Journal of Science Education and Technology, 25(1),* 127-147.

Yackel, E., & Cobb, P. (1996). Sociomathematical norms, argumentation, and autonomy in mathematics. *Journal for research in mathematics education*, 458-477.

APPENDIX A: DATA CORPUS AND ANALYSIS METHODS

<table>
<tr><th colspan="2">Data</th><th>Items / Materials needed</th><th>Personnel Involved</th><th>Article (s)</th><th>Analysis / Purpose</th></tr>
<tr><td rowspan="3">Design Meeting Recordings</td><td>Pre-Implementation</td><td>Audio Recorder</td><td>Design Team</td><td>3 and 4</td><td rowspan="3">Constant Comparative Analysis</td></tr>
<tr><td>During-Implementation</td><td>Audio Recorder</td><td>Design Team</td><td>3 and 4</td></tr>
<tr><td>Post-Implementation</td><td>Audio Recorder</td><td>Design Team</td><td>3 and 4</td></tr>
<tr><td rowspan="2">Classroom Recordings</td><td>Overall Class</td><td>Video Recorder</td><td>Teacher, Students</td><td>3 and 4</td><td rowspan="4">Toulmin's Model of Argumentation</td></tr>
<tr><td>Small Student Groups</td><td>Video/ Audio Recorder</td><td>Small Student Groups</td><td>3 and 4</td></tr>
<tr><td rowspan="2">Interviews</td><td>Focus Group</td><td>Video Recorder Protocol</td><td>Small Student Groups</td><td>3 and 4</td></tr>
<tr><td>Post- Class Reflection</td><td>Video Recorder Protocol</td><td>Teacher</td><td>3 and 4</td></tr>
<tr><td>Document Collection</td><td>Engineers' log</td><td>Activity Sheet</td><td>Students</td><td>3 and 4</td><td>Constant Comparative Analysis / For Data Triangulation</td></tr>
</table>

APPENDIX B: ENGINEERING BASED MATHEMATICAL INSTRUCTIONAL SEQUENCES

Residential Community - Phase II: Teacher Page

Overall Engineering Goal:

- Design and develop the layout of a residential community based on the given constraints

Overall Mathematical Goals:

Angles and Parallel Lines
(*Must be encouraged throughout this Sequence - Purposely Guided*)

- Analyze angle relationships to determine congruent angles
- Apply properties of triangles and parallel lines to solve problems

Scaling, Ratios and Proportions
(*Not guided but may appear in the Engineering Design Process*)

- Translate from one scale to another.
- Solve problems involving scale.
- Make connections between scale factor and the ratio of the lengths of corresponding sides

Students should be given a scaled down (to fit within a 11 x 17 paper) boundaries of the 48 acres of the land and the swamp area that cannot be developed along with the existing road connection points marked on it. Students will also be given several index cards cut outs that represent the scaled down area of 0.15 acres with the same scaling factor as the prior.

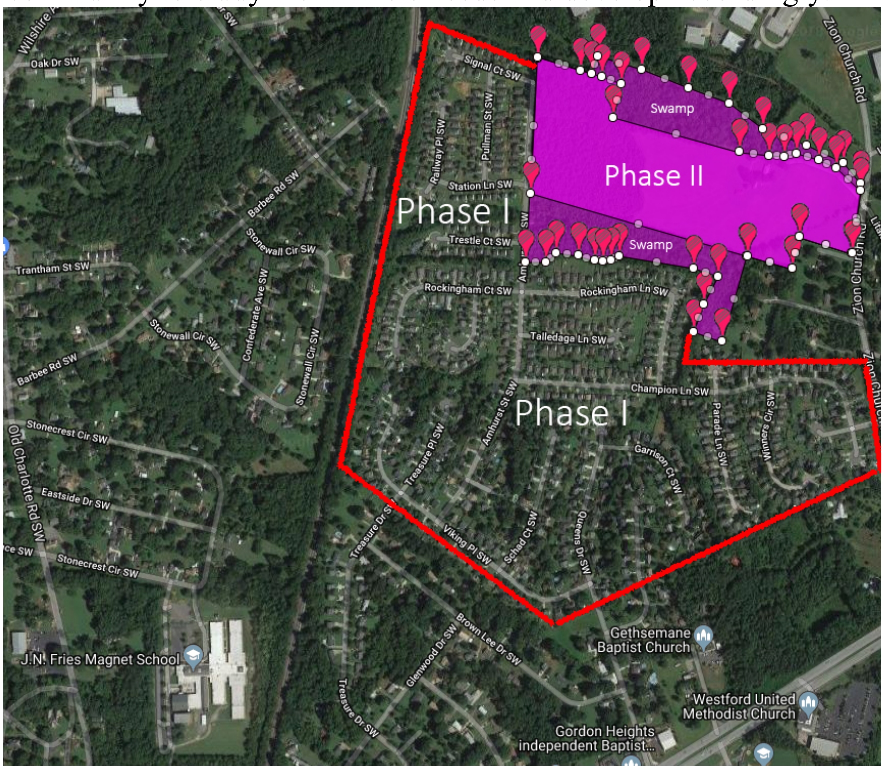
One of the design criteria will be guided through Specific Instructional tasks: New road MUST be parallel to Amhurst St SW and includes two rows of homes in between them with the back of the houses facing each other. Also extend Station Ln SW through Phase II and intersect with the new parallel road.

The sets of tasks (guided design criteria) is designed to encourage them to engage and think about parallel lines and the angles in them. After the first street is designed, the students are free to design the rest of the residential community based on the given design criteria.

Note: Design used in this document refers to the Engineering Design

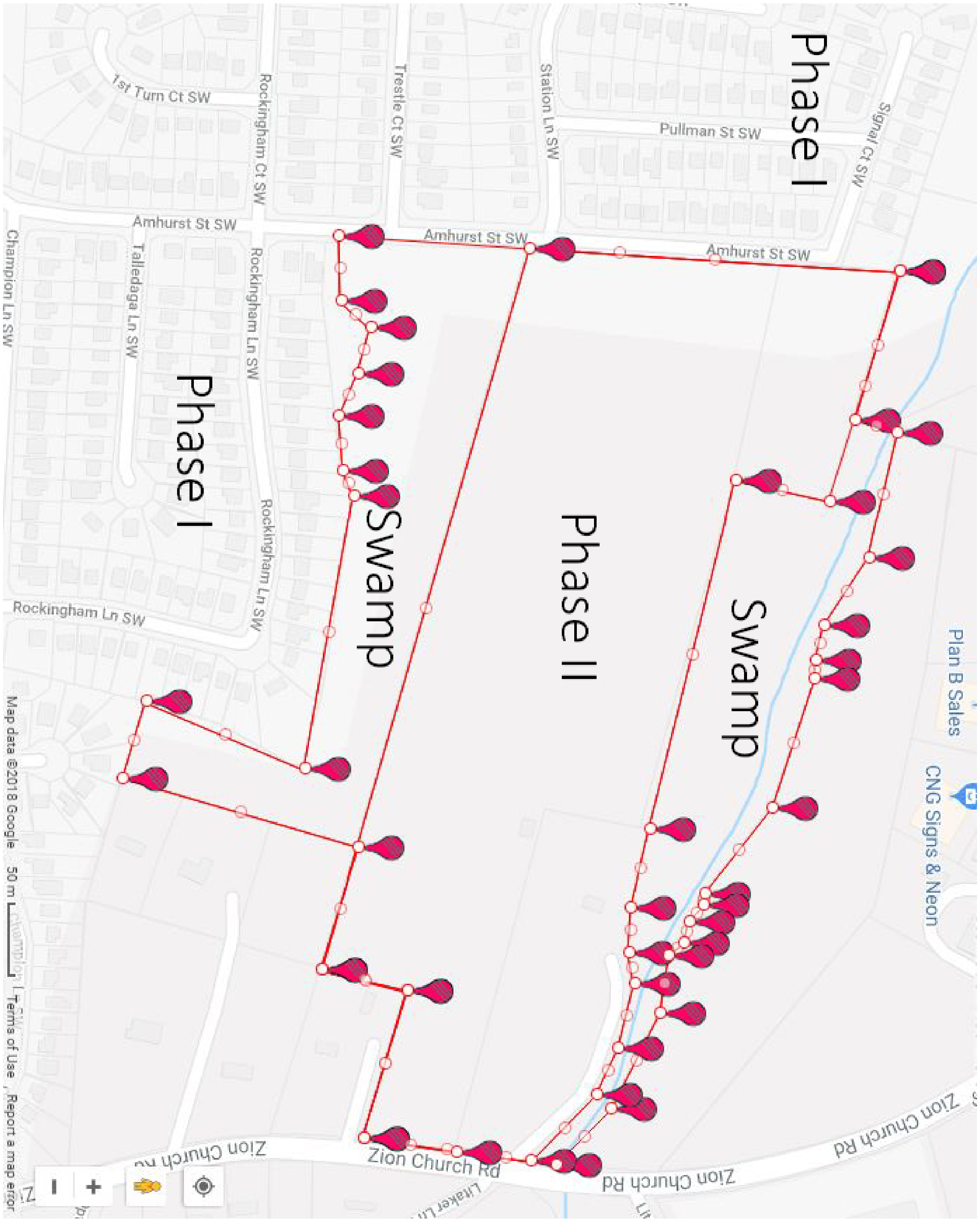
Residential Community - Phase II (Brief)

You are hired as the architect by a company that developed the phase I of a residential community to design and develop the layout of the phase II. The purchased the 218 acres and developed a part (170 acres) of it in phase I. These phases are staggered development of the land by the developer as a part of their strategy in developing the residential community to study the markets needs and develop accordingly.



The developer wants to include at least 100 homes with a minimum of 0.15 acres (~600 m^2) per home in the buildable area. He also wants you to include additional facilities for the community such as swimming pool, tennis court, basketball court, gym, and so on. For aesthetic reasons, developer wants the first row of homes to be parallel to the homes on the Amhurst St SW. So the new road MUST be parallel to Amhurst St SW and includes two rows of homes in between them with the back of the houses facing each other. Also the developer wants you to extend Station Ln SW through Phase II and intersect with the new parallel road.

You meet with the land surveyor and she tells you that Phase II will developed within the remaining available approximately 48 acres of land and approximately 17 acres (dark purple) of this available 48 acres is swamp that cannot be developed for any human use because of the protected wildlife in the swamp. Also, the City planner informs you that each road in the community must be at least 29 feet (~9m) wide and can include cul-de-sacs with a radius of at least 35 feet (~11 m) to meet the building code of your city.



Phase I
Phase I
Phase II
Swamp
Swamp
Amhurst St SW
Amhurst St SW
Amhurst St SW
1st Turn Ct SW
Rockingham Ct SW
Trestle Ct SW
Station Ln SW
Pullman St SW
Signal Ct SW
Champion Ln SW
Talledaga Ln SW
Rockingham Ln SW
Rockingham Ln SW
Rockingham Ln SW
Zion Church Rd
Zion Church Rd
Zion Church Rd
Zion Church Rd
Plan B Sales
CNG Signs & Neon
Map data ©2018 Google
50 m
Terms of Use
Report a map error

Residential Community - Phase II

Know	Prior Knowledge	Need to Know

Exit Slip

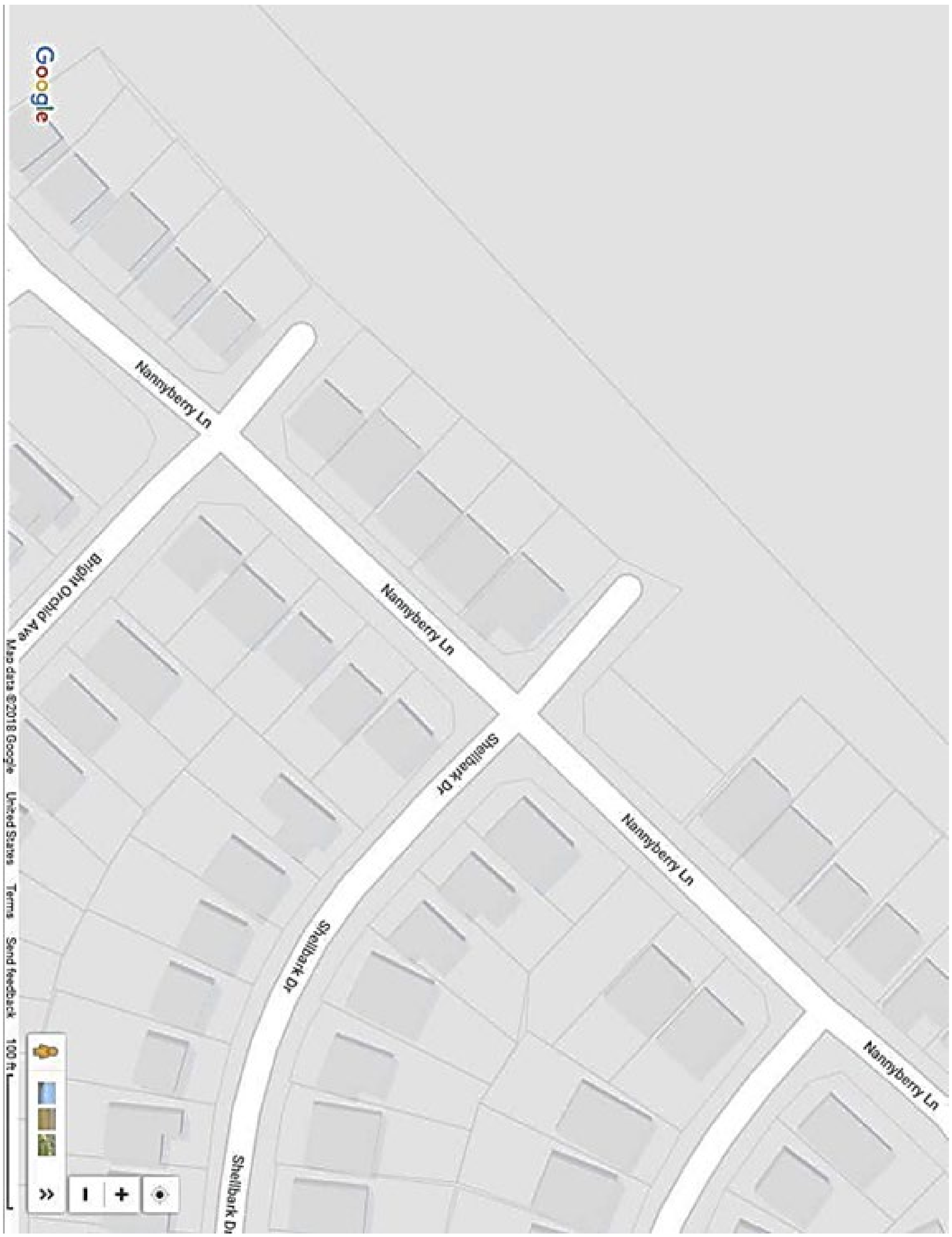
Draw a parallel to the line A below	Describe your Strategy

Parallel Roads Part 1

Remember, the new road must be parallel to Amhurst St SW. Also, you must have two rows of homes in between the new road and Amhurst St SW. Also extend Station Ln SW through Phase II and intersect with the new parallel road.

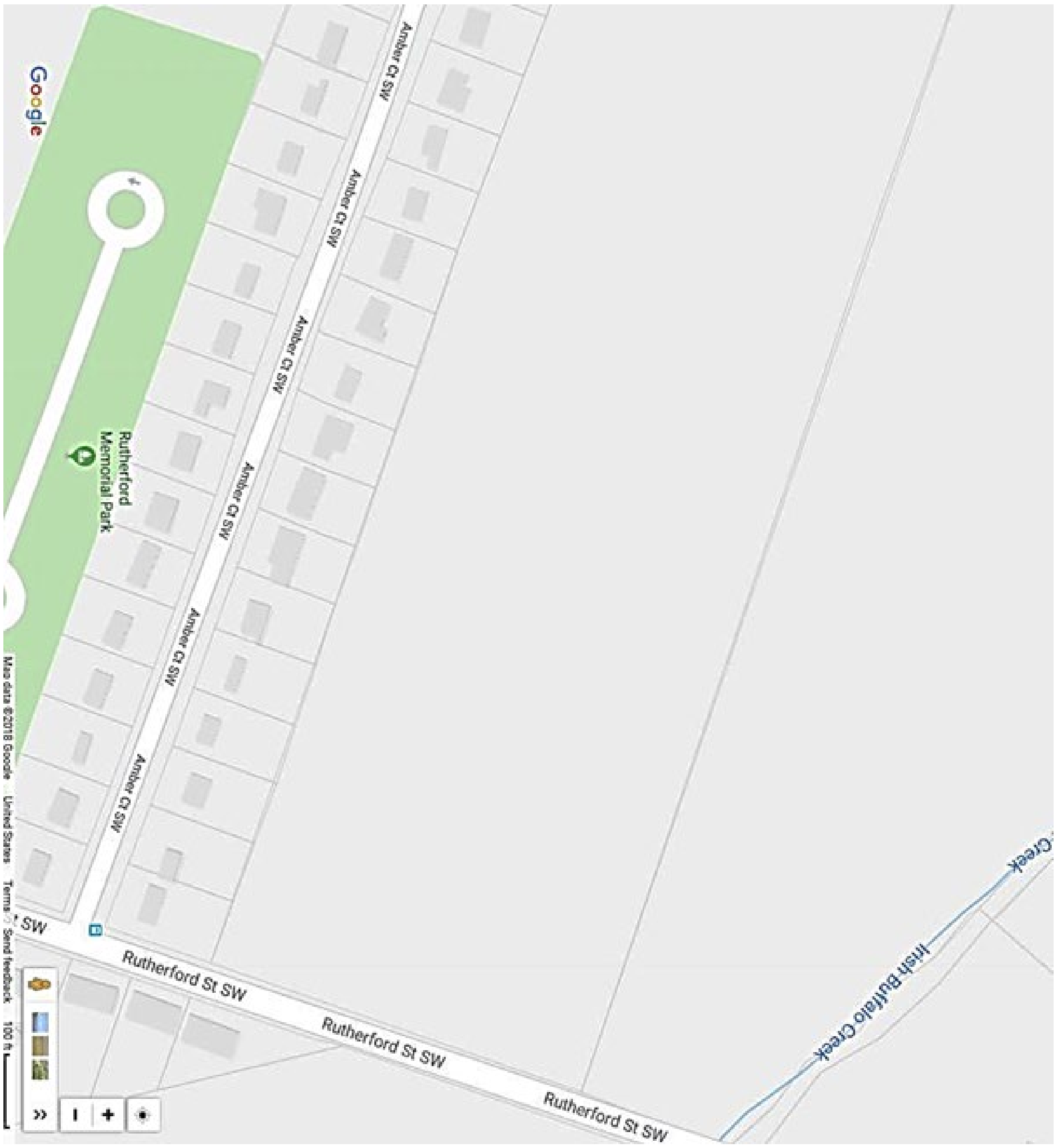
Parallel Roads Part 2

Your colleague working on an another project has a similar scenario and needs your help. Help him draw a road parallel to Nannyberry Ln with two rows of houses in between. Also, extend Bright Orchid Avenue and Shellbark Dr further to intersect with new parallel road.



Parallel Roads Part 2

The same colleague is now back asking for your help with another similar scenario. Help him draw a road parallel to Amber Ct SW. There should be two rows of houses in between the new road and Amber Ct SW. The new parallel road should intersect with Rutherford St SW similar to Amber Ct SW.



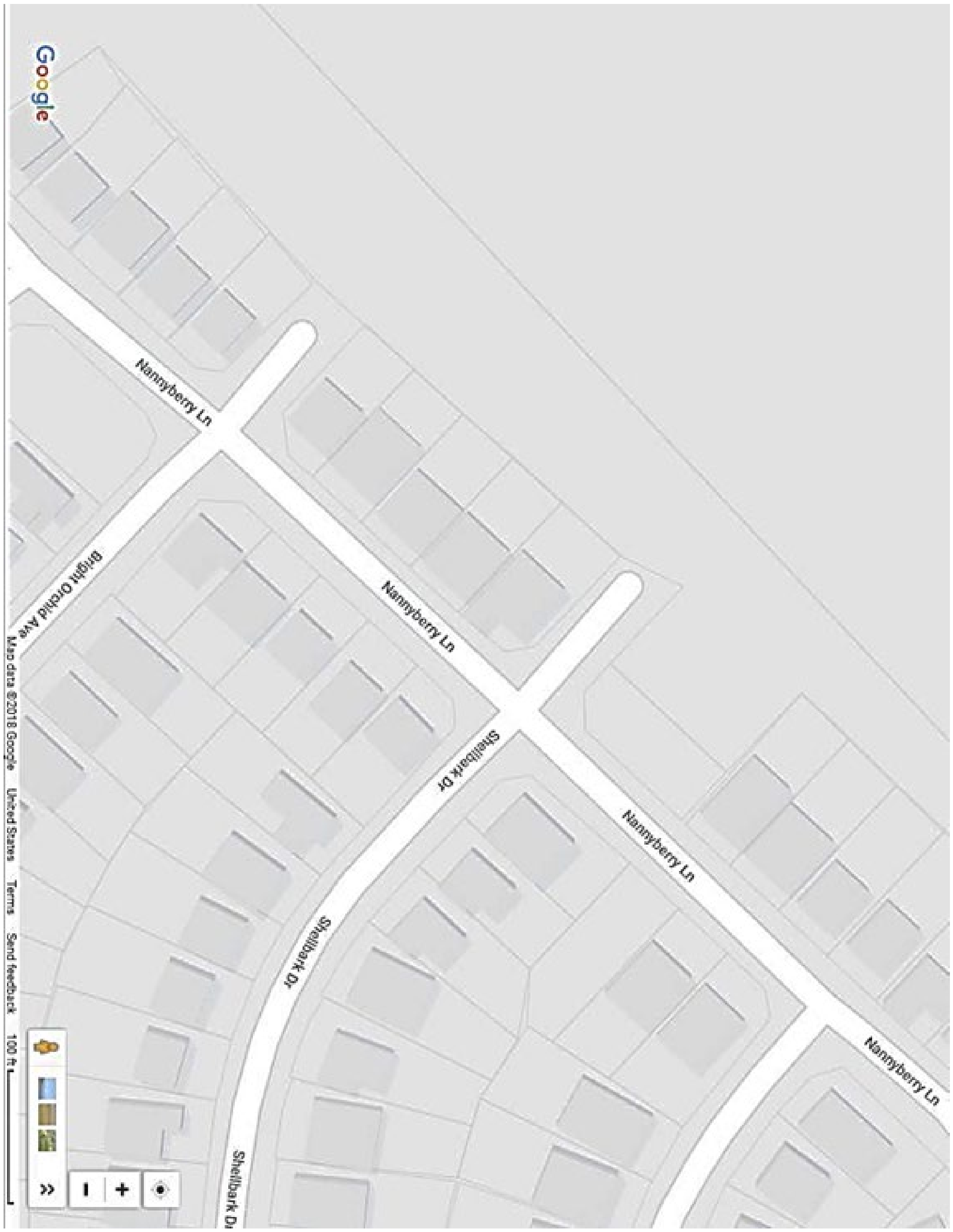
Help him understand your reasoning on how you drew your parallel roads so he does not have to rely on you everytime.

Civil Engineer's Dilemma

You meet with the road construction engineer to share your new road layout and she tells you that using just the distance between the roads will be difficult to construct the actual road and also that the current angle between Amhurst St SW and Station Ln SW is 95^0 and she used angles to ensure that Pullman St SW and Amhurst St SW are parallel. Can you use this new information on angles to ensure that the new road is parallel to Amhurst St SW?

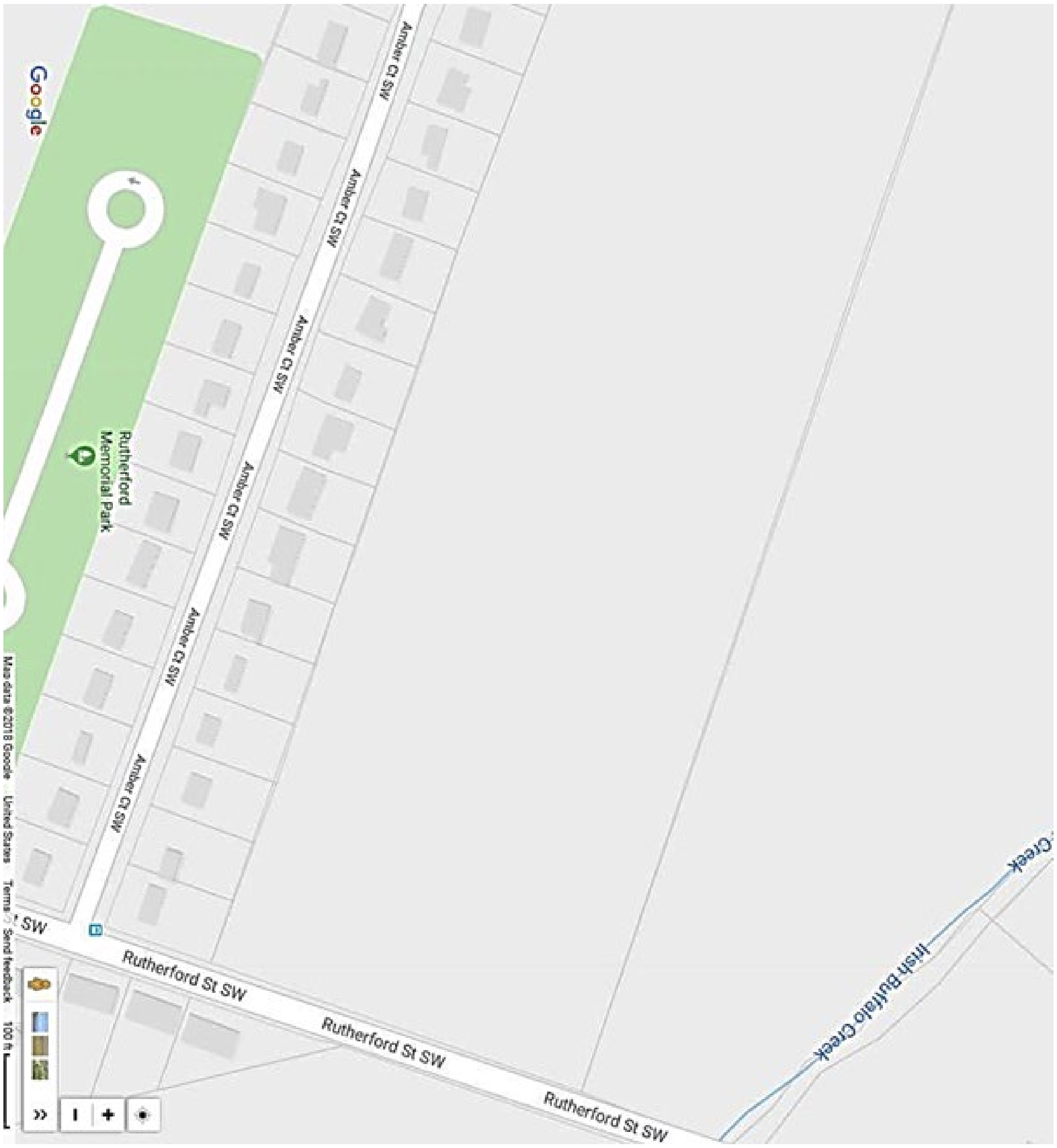
Parallel Roads Part 3

You check your reasoning with your colleague's scenarios and you learn from him that the current angle between Nannyberry Ln and Bright Orchid Ave is 90^0.



Parallel Roads Part 3

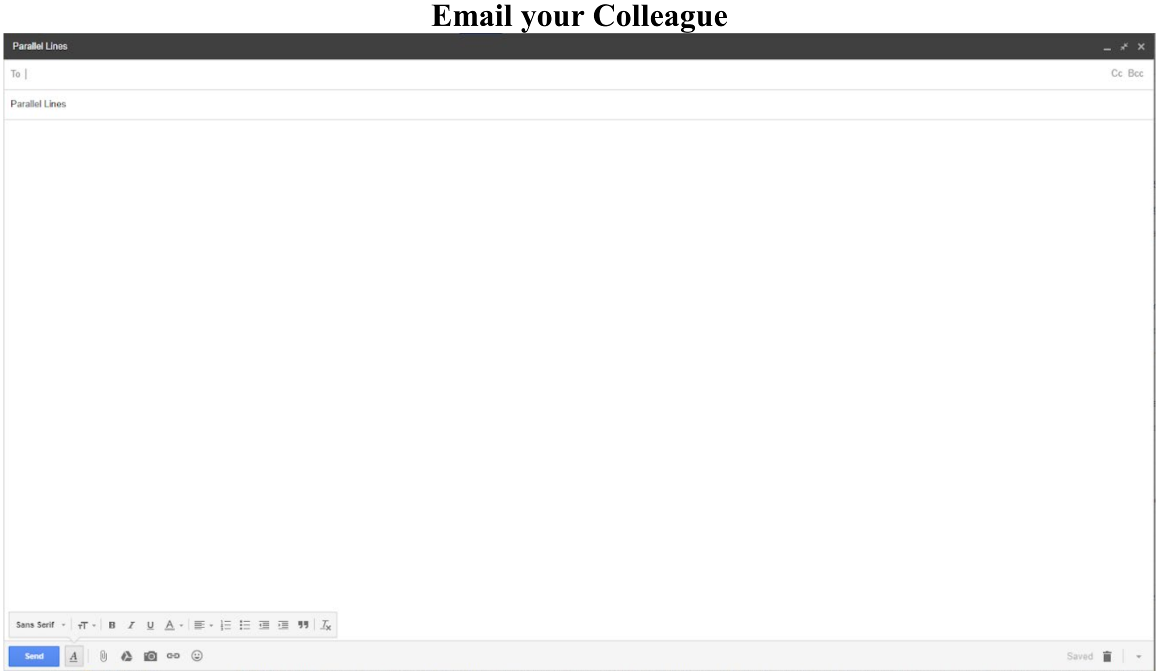
Also the current angle between Amber Ct SW and Rutherford St SW is 90^0. Help him understand with your new reasoning on using angles for parallel roads.



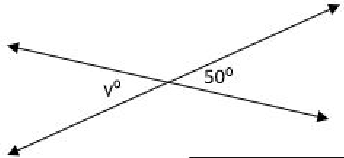
Exit Slip: Charamont Dr SW

Find the angles of intersection on Charamont Dr SW with Larkview Dr SW and Green St SW given that the current angle between Kingfield Dr SW and Larkview Dr SW is 79^0

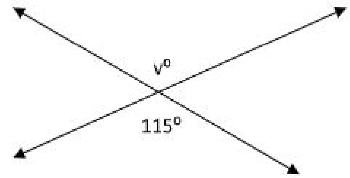
Email your Colleague

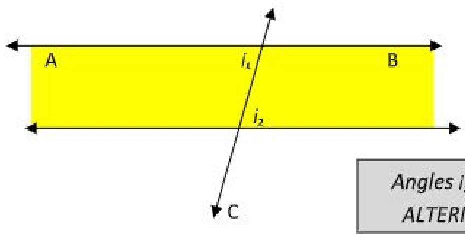


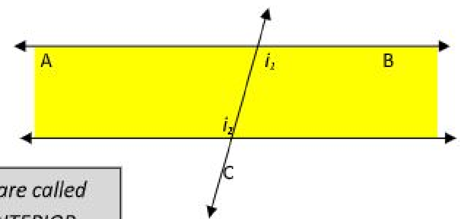
Vicious Vocabulary



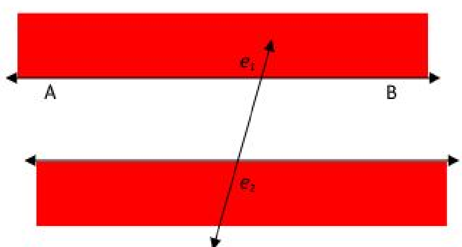
Vertical angles are the angles that are opposite each other

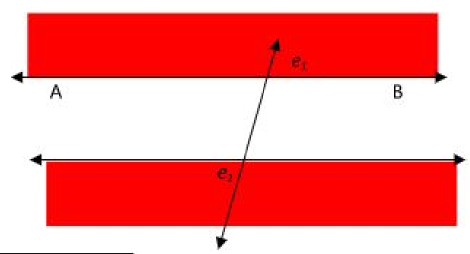




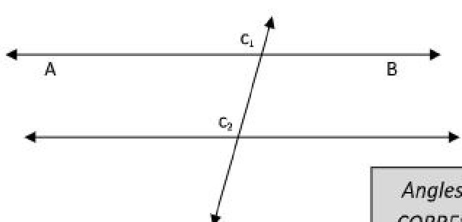


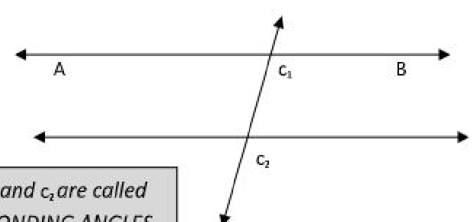
Angles i_1 and i_2 are called ALTERNATE INTERIOR





Angles e_1 and e_2 are called ALTERNATE EXTERIOR

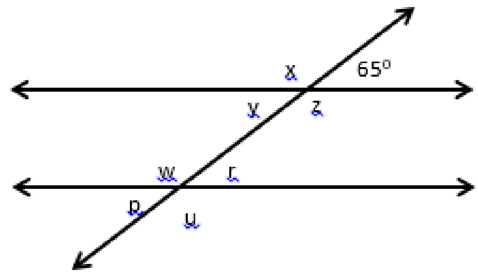




Angles c_1 and c_2 are called CORRESPONDING ANGLES

Name the Intersection – Page 1 of 2

Determine the missing angle measures. Use the vocabulary words in the box to give your reasons.



Angle A = ________ *because they are* ___________

Angle B = ________ *because they are* ___________

Angle C = ________ *because they are* ___________

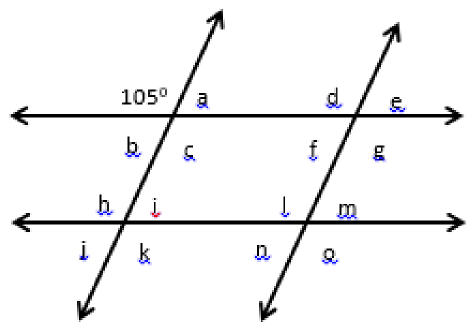
Angle D = ________ *because they are* ___________

Angle E = ________ *because they are* ___________

Angle F = ________ *because they are* ___________

Angle G= ________ *because they are* ___________

Vocabulary
Supplementary angles
Corresponding angles
Vertical angles
Alternate interior angles
Alternate exterior angles



Angle a = __________ Because

Angle b= __________ Because

Angle c = __________ Because

Angle d = __________ Because

Angle e = __________ Because

Angle f = __________ Because

Angle g = __________ Because

Angle h = __________ Because

Angle i = __________ Because

Angle j = __________ Because

Angle k = __________ Because

Angle l = __________ Because

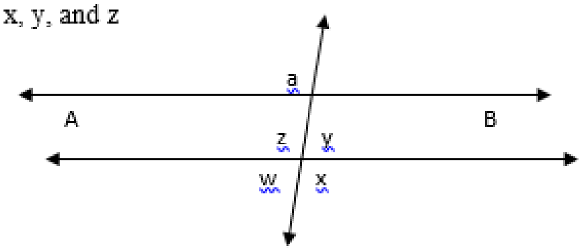
Angle m = __________ Because

Angle n = __________ Because

Angle o = __________ Because

Name the intersection – Page 2 of 2

1. Name an angle that is alternately exterior to ∠a. If ∠a is 100^0, find the missing angles w, x, y, and z



2. Find each angle and provide your proof:

Angle x =

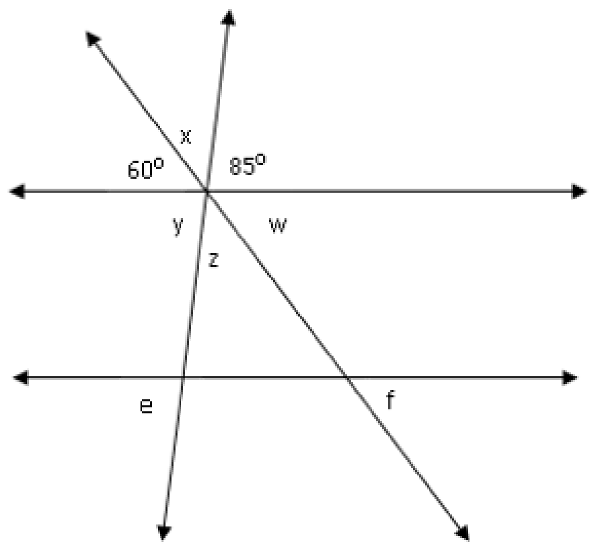
Angle y =

Angle z =

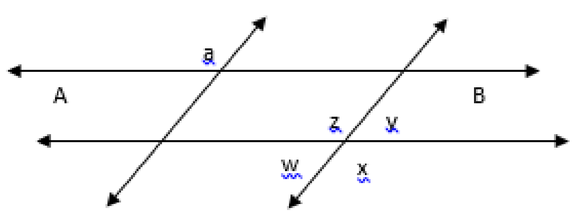
Angle w =

Angle e =

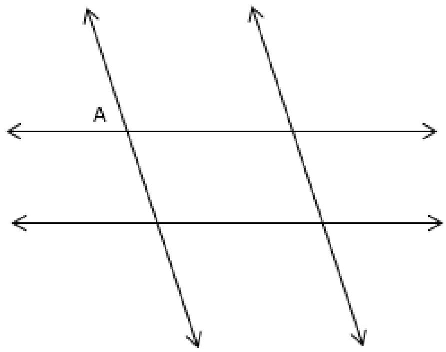
Angle f =



3. Name an angle that is supplementary to ∠z. If a is 130^0, find the missing angles w, x, y, and z

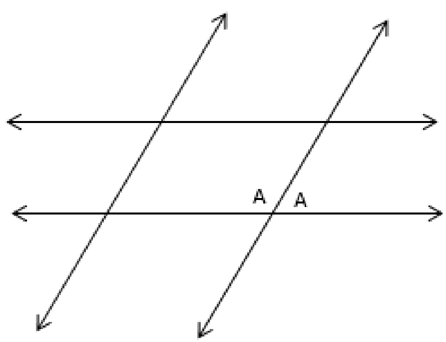


Down Town Angle Ville (Additional)



1. Mark angle(s) that are **alternately exterior** to Angle A.

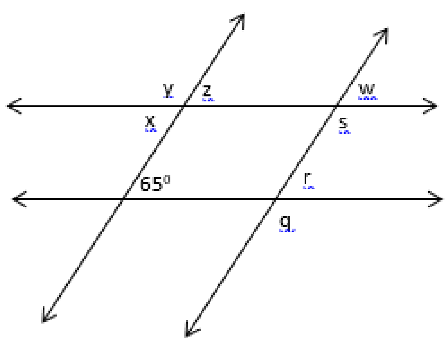
2. Mark angle(s) that **corresponds** with Angle A.



3. Mark angle(s) that are **alternately interior** to Angle A.

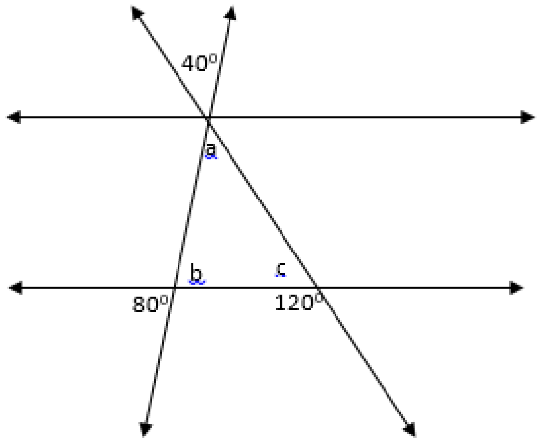
4. Name an angle(s) that **corresponds** with Angle A.

5. Mark angles that are **supplementary** to Angle A



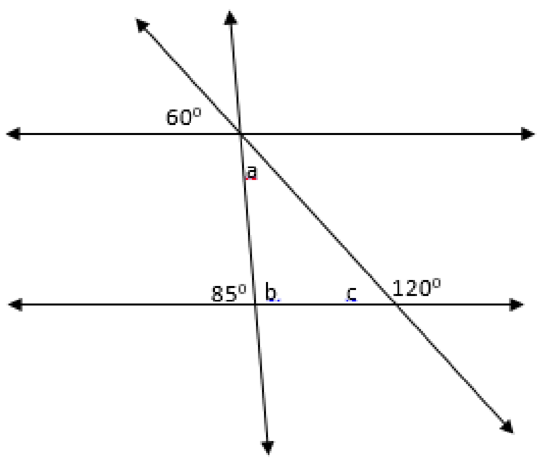
6. **Find the missing angles. Provide proof.**

Triangulation (Additional)



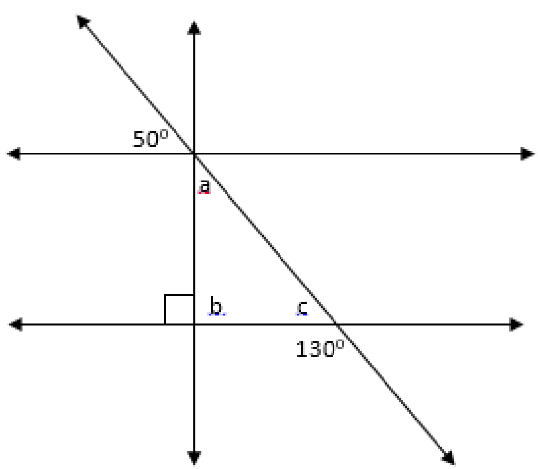
1. Find the sums of angles a, b, and c.

a + b + c =



2. Find the sums of angles a, b, and c.

a + b + c =



3. Find the sums of angles a, b, and c.

a + b + c =

Road Construction

Now that you have figured out a parallel road, the road construction engineer met with a manufacturer the makes modular triangular road blocks which can be tiled to form a road. A 28 ft (L) by 29 ft (W) of these modular triangular road blocks cost $1000. He is trying to figure out a cost efficient way to lay these modular blocks to construct the road and needs an architect's opinion on the same. Here is a section of the road that he is tiling with these modular blocks, can you tile it and look for any patterns that may emerge to calculate the cost efficiently.

	Road Width: 29 feet (~9m)	
Road Length: xxfeet (~xxm)	To be tiled area	Road Length: xxfeet (~xxm)
	Road Width: 29 feet (~9m)	

Residential Community - Phase II

(Print on 11 x 17 Sheet of Paper)

A Two Story Home: Teacher Page

Overall Engineering Goal:

- Design and construct a miniature model of a two-story home based on the given constraints

Overall Mathematical Goals:

Scaling, Ratios and Proportions, Angles and Parallel Lines
(*Open - Design criteria must encourage these*)

- Analyze angle relationships to determine congruent angles
- Apply properties of triangles and parallel lines to solve problems
- Dilate to produce similar geometric objects.
- Translate from one scale to another.
- Solve problems involving scale.
- Analyze different figures to determine congruence, scale factor and proportionality.
- Make connections between scale factor and the ratio of the lengths of corresponding sides
- Reflect, translate, and rotate to produce congruent geometric objects.

Students will be given a layout of the street with plots for 10 (based on # of student groups) homes (each plot must be at least fit an 11 x 17 paper). Each student teams will pick a plot of land and design a two-story home for the plot based on the design constraints.

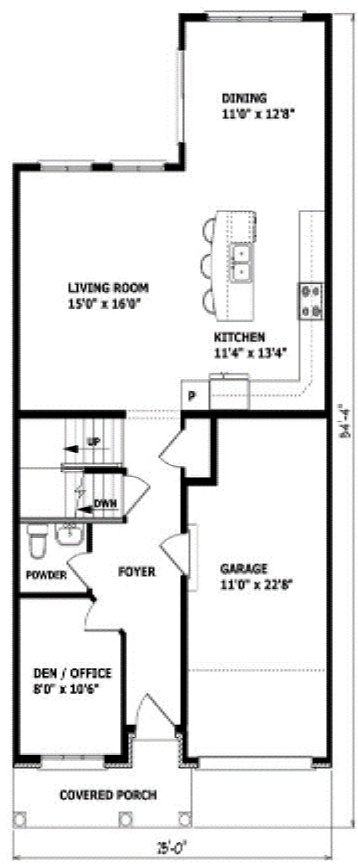
Note: Design used in this document refers to the Engineering Design

A Two Story Home

Now continuing the design of phase II of the community, you are asked by the developer to design and develop of a two-story home. Based on the homes sold in Phase I, the developer informs you that each home must include at a minimum of 4 bedrooms and 3.5 baths, a kitchen, formal dining and breakfast area, living room, home office and a game room, a two-car garage, and driveway for one additional car parking.

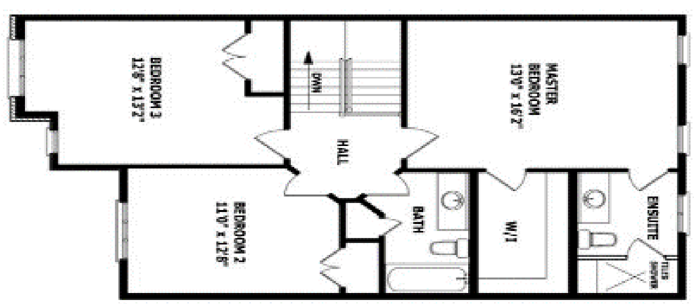
In order to keep the home prices consistent in the entire community, developer asks you to keep the overall area (first and second floor combined) of the home similar that is must be at least 2500 sq.ft and a maximum of 3500 sq. ft.

The residential community sales office wants you to build a miniature model of the home using foam board for displaying it potential customers. They also want floor plans (blueprint of each floor) that are scaled to fit on 8.5 x 11 paper to hand out to the customers.



1ST FLOOR PLAN

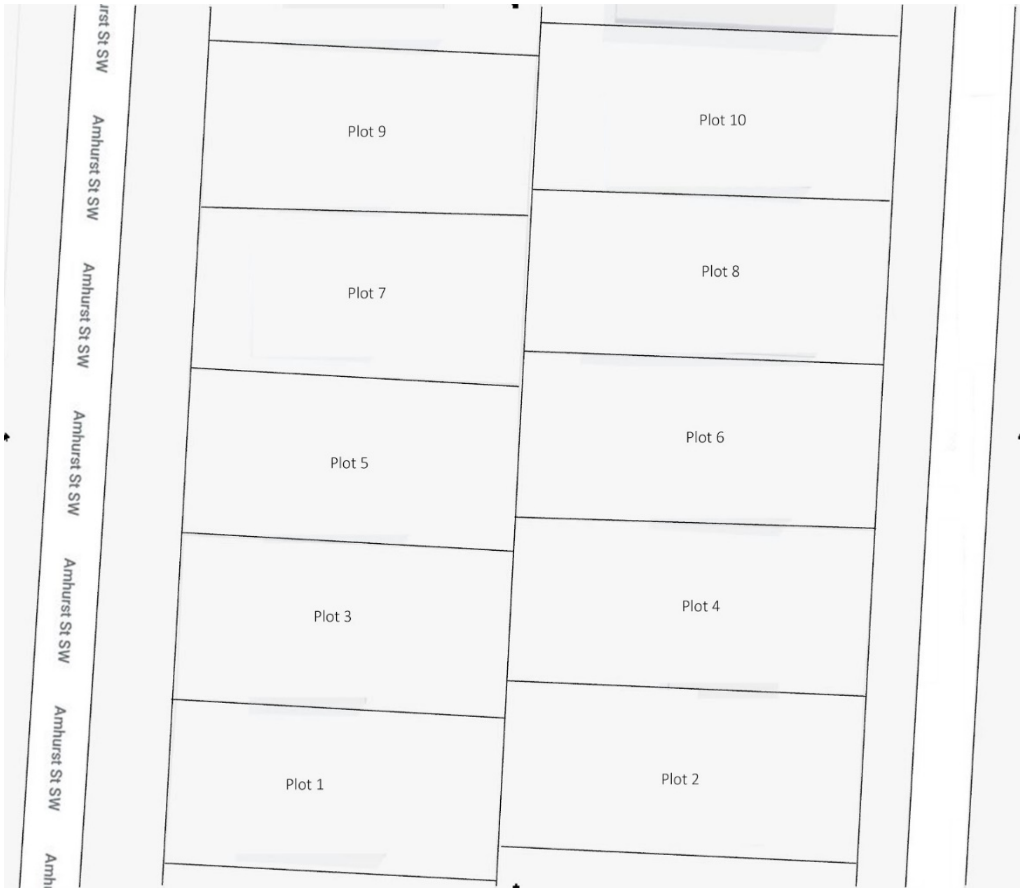
GROSS FLOOR AREA : 866 SQ.FT.



2ND FLOOR PLAN

GROSS FLOOR AREA : 868 SQ.FT.

A Two Story Home
Available Plots of Land
(Split the image and print on Four 22 x 28 Poster Boards)



Floor Plan Scaling

• Walls: 6 in or 0.5 ft • Bed, Queen: 5 ft x 7 ft • Bed, Twin: 3 ft x 6 ft • Toilet: Standard 1 ft x 2 ft • Counter: 2 ft deep • Kitchen Sink: 1 ft x 2 ft • Bathtub: 3 ft x 5 ft • Shower 3 ft x 3 ft or 2 ft x 4 ft • Oven/range: 2.5 ft wide x 2 ft deep • Refrigerator: 2 ft x 2 ft • Couch: 3 ft x 4 ft or 3 ft x 6 ft • Kitchen table: 3 ft round or 3 ft x 3 ft square • Closets: Designed as you wish. Remember that you must have 6-inch walls. • Doors: 2.5 ft or 3 ft wide (The front door must be 3 ft.) • Standard size of drawing room may range from: 4200mm (14ft) X 4800 mm (16ft) to 5400mm (18ft) X 7200mm (24ft) • Standard size of bedrooms may range from: 3000mm (10ft) X 3600mm (12ft) to 4200mm (14ft) X 4800mm (16ft) • Standard size of guest rooms may be: 3000mm (10ft) X 3600mm (12ft) • Standard size of office room may be: 3000mm (10ft) X 3600mm (12ft) • Size of Dining rooms may range from: 3600mm (12ft) X 4200mm (14ft) to 4200mm (14ft) X4800mm (16ft) • Standard size of kitchen rooms may range from: 2500mm (8ft) X 3900mm (13ft) to 3000mm (10ft) X 3600mm (12ft) • Standard size of store room may range from: 2500mm (8ft) X 2500mm (8ft) to 3000mm (10ft) X 3000mm (10ft) • Size of pantry may range from: 2500mm (8ft) X 3000mm (10ft) • Common sizes of bathroom and water closet may be: 1200mm X 1800mm • Ceiling height of not less than 7 feet (2134 mm)	**Actual Dimension**	**Blueprint/Model Scaling Factor** =
		Blueprint/Model Dimension

Peer Evaluation

Name: ________________________________

On a scale of 1 to 5, with 1 meaning rarely or very little and 5 meaning often or quite a lot, rate your team-mate's effectiveness/contribution in the following areas;

Evaluation Criteria	Group member Name:	Group member Name:	Group member Name:	Group member Name:
Listened to and respected the ideas of others.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Contributes meaningfully to group discussions.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Did their share when working in a group.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Concentrated when working.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Demonstrates a cooperative and supportive attitude.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Contributes significantly to the success of the project.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
TOTALS				