

1-26-2024

## “That Cross-Curricular Business”: The Engineering Design Process in Mathematics and Science Classrooms

Eugenia Vomvoridi-Ivanovic  
*University of South Florida, eugeniav@usf.edu*

Tonisha B. Lane  
*Virginia Polytechnic Institute and State University, tblane@vt.edu*

Leia K. Cain  
*The University of Tennessee, LeiaCain@utk.edu*

Salam Ahmad  
*University of South Florida, saahmad1@usf.edu*

Selene Willis  
*The Ingenuity Project, Inc.*

*See next page for additional authors*

Follow this and additional works at: <https://nsuworks.nova.edu/tqr>



Part of the [Science and Mathematics Education Commons](#)

---

### Recommended APA Citation

Vomvoridi-Ivanovic, E., Lane, T. B., Cain, L. K., Ahmad, S., Willis, S., & Gaines, J. E. (2024). “That Cross-Curricular Business”: The Engineering Design Process in Mathematics and Science Classrooms. *The Qualitative Report*, 29(1), 355-376. <https://doi.org/10.46743/2160-3715/2024.6065>

This Article is brought to you for free and open access by the The Qualitative Report at NSUWorks. It has been accepted for inclusion in The Qualitative Report by an authorized administrator of NSUWorks. For more information, please contact [nsuworks@nova.edu](mailto:nsuworks@nova.edu).



## “That Cross-Curricular Business”: The Engineering Design Process in Mathematics and Science Classrooms

### Abstract

The engineering design process (EDP) is one tool teachers can use to facilitate STEM integration. As part of a larger three-year longitudinal research project regarding engineering identity development among middle school youth in a summer robotics outreach program, this study aims to understand teachers’ willingness to incorporate engineering design in their classrooms through an exploration of their perceptions of the EDP, its applications to their subject matter and classroom context, methods of enacting the EDP, and perceived challenges to and supports for doing so. We conducted a qualitative case study and drew our results from focus groups and semi-structured interviews with eight teacher participants. Participants were successful in describing the EDP and its cyclical nature. However, classroom enactment of the EDP was predominantly indirect and often used to solve non-subject-specific classroom problems. Direct enactment was limited to projects already part of the existing curriculum. Issues with instructional resources, lesson planning, time, and student background were the EDP enactment barriers most frequently noted, while supports described were all responses to the identified barriers. The EDP offers a promising way to integrate engineering with math and science. However, additional support is needed for more meaningful classroom enactment of the EDP.

### Keywords

case study, teacher professional development, engineering design, STEM integration

### Creative Commons License



This work is licensed under a [Creative Commons Attribution-Noncommercial-Share Alike 4.0 International License](https://creativecommons.org/licenses/by-nc-sa/4.0/).

### Authors

Eugenia Vomvoridi-Ivanovic, Tonisha B. Lane, Leia K. Cain, Salam Ahmad, Selene Willis, and Jonathan E. Gaines

## “That Cross-Curricular Business”: The Engineering Design Process in Mathematics and Science Classrooms

Eugenia Vomvoridi-Ivanovic<sup>1</sup>, Tonisha B. Lane<sup>2</sup>, Leia K. Cain<sup>3</sup>,  
Salam Ahmad<sup>1</sup>, Selene Willis<sup>4</sup>, and Jonathan Gaines<sup>5</sup>

<sup>1</sup>University of South Florida, Tampa, Florida, USA

<sup>2</sup>Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA

<sup>3</sup>University of Tennessee-Knoxville, Tennessee, USA

<sup>4</sup>The Ingenuity Project, Inc., Baltimore, Maryland, USA

<sup>5</sup>Georgia Institute of Technology, Georgia, USA

---

The engineering design process (EDP) is one tool teachers can use to facilitate STEM integration. As part of a larger three-year longitudinal research project regarding engineering identity development among middle school youth in a summer robotics outreach program, this study aims to understand teachers' willingness to incorporate engineering design in their classrooms through an exploration of their perceptions of the EDP, its applications to their subject matter and classroom context, methods of enacting the EDP, and perceived challenges to and supports for doing so. We conducted a qualitative case study and drew our results from focus groups and semi-structured interviews with eight teacher participants. Participants were successful in describing the EDP and its cyclical nature. However, classroom enactment of the EDP was predominantly indirect and often used to solve non-subject-specific classroom problems. Direct enactment was limited to projects already part of the existing curriculum. Issues with instructional resources, lesson planning, time, and student background were the EDP enactment barriers most frequently noted, while supports described were all responses to the identified barriers. The EDP offers a promising way to integrate engineering with math and science. However, additional support is needed for more meaningful classroom enactment of the EDP.

*Keywords:* case study, teacher professional development, engineering design, STEM integration

---

### Introduction

While the U.S. economic advantage within the global market is directly related to innovation, problem solving skills, and technical literacy, there is a critical need for more scientists and engineers (Institute of Medicine, 2007; President's Council of Advisors on Science and Technology [PCAST], 2012). Additionally, U.S. student achievement levels continue to lag behind those of their international counterparts. The National Research Council (NRC) has responded with Next Generation Science Standards to expose K-12 students to practices and methodologies that use content-appropriate material (NRC, 2011), and Science Technology Engineering and Mathematics (STEM) integration has been identified as a vehicle to accomplish these goals (Margot & Kettler, 2019). Engineering design may be particularly important for STEM learning as (1) engineering can be introduced as a noble profession that helps the community, (2) design teams can benefit from cultural diversity and are cooperative

in nature, (3) engineering problems can be open-ended and rely on inquiry and critical thinking skills, and (4) engineering design teams often support the development of twenty-first century skills (National Academies of Science, Engineering and Medicine, 2020).

To address the challenge to actualize engineering education in the K-12 curriculum specifically, the NRC published *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* (Katehi et al., 2009). According to this report, among the many benefits of incorporating engineering into the curriculum was boosting student achievement and motivation. However, the report contained little information about how to “do” engineering in K-12 education and provided few tangible strategies to help teachers integrate engineering components into their classrooms (Dare et al., 2018). More recently, the National Academies of Sciences, Engineering, and Medicine (2020) published *Building Capacity for Teaching Engineering in K 12 Education*, which argued for the need to increase ongoing professional development to support teachers in incorporating engineering into their math and science courses. It also noted the limited information available concerning how teacher education programs were preparing teachers for STEM integration in the classroom. Despite these reports and existing literature on STEM integration, we still know little about how mathematics and science teachers perceive and enact engineering education in their curriculum.

One of the few studies to explore teachers’ implementation of engineering design uncovered that resources, training, and support were among the needs for teachers to integrate engineering education into their pedagogy (Hammack & Ivey, 2019). However, this study only focused on K-5 elementary teachers. Other issues raised in the literature are that few mathematics and science teachers have engineering backgrounds (Martin et al., 2015) and the paucity of professional development opportunities for integrating engineering design into their classrooms (Roehrig et al., 2012). Therefore, most of the mathematics and science teachers lack engineering experience, and thus struggle to implement meaningful engineering design opportunities into their teaching (Katehi et al., 2009). Research that explores the practices of teachers who successfully achieve engineering integration is limited (Dare et al., 2018; Wang et al., 2011). To this end, the purpose of this paper is to report findings from a qualitative, in-depth case study (Yin, 2009) that examines mathematics and science teachers’ (MSTs’) perceptions of the engineering design process (EDP) and its enactment in mathematics and science teaching. We draw from a larger study situated in Bulls-Engineering Youth Experience (Bulls-EYE), a summer engineering robotics program, that includes MSTs who serve as mentors to middle school youth in the program. We then conclude with implications for teacher educators.

## Literature Review

Developing more integration among STEM-related disciplines is a necessary endeavor. Nevertheless, few studies specifically highlight engineering design-based professional development (Estapa & Tank, 2017). Our literature review unpacks STEM integration and the role of professional development in actualizing STEM integration. Additionally, it discusses how the EDP can be a conduit for realizing STEM integration in K-12 classrooms. We also identify potential barriers and opportunities for integrating STEM disciplinary content into the classroom.

### Benefits and Challenges of STEM Integration

The need to teach mathematics and science in a STEM-integrated manner is gaining traction in education literature (Margot & Kettler, 2019). The *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research* (NAE & NRC, 2014) report

emphasized that addressing the critical problems of today's society and those that will arise in the future will require students to become adept at making connections among STEM disciplines. According to Kelley and Knowles (2016), "instead of teaching content and skills and hoping students will see the connections to real-life application, an integrated approach seeks to locate connections between STEM subjects and provide a relevant context for learning the content" (p. 3). Yet, a recent study showed that teachers may be challenged by maintaining a motivating and engaging classroom environment while connecting STEM subjects (Dare et al., 2018). In a phenomenological multiple case study with 48 teachers from three school districts, Dare et al. (2018) found teachers taught STEM subjects in a siloed manner instead of intentionally integrating them. As noted by the researchers, this may have been due to the teachers' backgrounds in the sciences rather than math or engineering, where they tended to emphasize their lessons. Dare et al. (2018) also concluded that the extent to which teachers can integrate STEM subjects would depend on their capacity to "make explicit and meaningful connections between subjects" (p. 17). To this end, interdisciplinary and transdisciplinary STEM integration, necessary for learning and applying STEM knowledge and skills, is a persistent problem in K-12 school contexts (English, 2016; Vasquez et al., 2013).

Further, there are several challenges with STEM integration and enacting the EDP in the classroom environment. Bybee (2013) posited that integrative STEM teaching could not be done quickly and requires careful planning and purposeful action for improvement. It requires successful integration of technology and engineering, introduction of real-world STEM-related challenges into classroom curricula, and introducing STEM as a well-defined goal, not a slogan or buzzword science and math teachers use. The focus of STEM integration is currently muddled, and its theory and aims are difficult to realize in the classroom, especially since teachers with less engineering experience are less comfortable integrating technology with other STEM components (Johnson et al., 2020).

Research suggests that teachers' enactment of STEM integration has had mixed effects. In their study of elementary teachers' engineering efficacy, Hammack and Ivey (2019) found that in addition to professional development opportunities being limited, their effectiveness varies greatly, and their long-term effects have yet to be determined. Teachers also need more in-service training that directly impacts classroom instruction to help develop curricular resources. Other researchers note that teachers are challenged by a lack of classroom implementation models that support the development of authentic curriculum, i.e. curriculum that students can relate to (King & Wiseman, 2001; Moore et al., 2014). Just like the EDP, curriculum design is an iterative process that requires time, testing, and revising, which may not be accessible to teachers.

Access and equity-based challenges also limit teachers' abilities to enact their developed models. Moore et al. (2014) explain that STEM lessons require a significant number of materials and resources for students to investigate possible solutions to real-world problems through designing, expressing, testing, and revising their ideas. Not all schools have equal technology, materials, or resources. Teachers can also be very apprehensive about teaching integrative STEM content due to a lack of confidence in engineering content, especially in elementary school contexts (Guzey et al., 2014; Hsu et al., 2011). They may also be reluctant to implement such content if they do not believe it will benefit their students (Ring et al., 2017). Some studies report that teachers do not feel students are motivated or may have deficit perspectives about what their students can do and achieve (Holstein & Keene, 2013).

Martin et al. (2015) also highlighted the challenges schools face in providing STEM-centered coursework. Because there are not enough engineering-trained teachers to instruct specific integrated STEM classes, MSTs are filling this gap. However, engineering requires a different method of problem solving, using ill-structured scenarios and design-based challenges that MSTs may find difficult to implement (Douglas et al., 2016; Martin et al.,

2015). Guzey et al.'s (2014) case study of in-service elementary teachers revealed that teachers occasionally bypassed the re-design step of the EDP to save time. However, the re-design step is critical to the iterative process, allowing students to improve based on their observations and learn from failure. Without a background in these areas, science and math teachers may struggle without a strong and malleable understanding of core engineering content coupled with the ability to think fluidly in novel situations (Martin et al., 2015; Silvestri et al., 2019). Martin et al. (2015) concluded that STEM teacher preparation programs are best served by providing teachers with experiences that use basic engineering design knowledge in a fluid and flexible manner via adaptive expertise and challenge-based instruction.

### **Professional Development as a Mechanism for Supporting STEM Integration**

Research demonstrates that some of the challenges teachers face can be addressed through professional development programs. In a qualitative study with 33 MSTs participating in a yearlong professional development for STEM integration, researchers concluded that teachers could be more successful with integrating interdisciplinary content into their curriculum if they had adequate technical support, common planning times, and continuous professional development (Herro et al., 2019). The *Standards for Preparation and Professional Development for Teachers of Engineering* (Reimers et al., 2015), curated by the American Society of Engineering Education lists several components that should be included in engineering training programs for teachers. These include creating professional growth opportunities for teachers and assessing program impacts on teachers' engineering and teaching efficacy. What is clear is that teachers need well-defined professional development that allows in-depth understanding of the "purpose of the materials and first-hand experience with some of the difficulties students might encounter" (NRC, 2009, p. 103).

Further, the way teachers conceptualize STEM integration is evident in their methods of curriculum development; however, there is little research on science teachers' development and implementation of integrated STEM units (Guzey et al., 2014). Of note, Ring et al. (2017) conducted a three-week professional development seminar with science teachers that explored teachers' conceptions of STEM integration. MSTs were asked to visually represent their conceptions of integrated STEM education using a STEM reflection protocol. The findings led to eight major models of STEM integration that represented the variety of ways teachers imagine integration. One such model included science and engineering design processes as context, which involved teachers beginning to place equal emphasis on teaching scientific and mathematical concepts and the engineering design process, using technology when appropriate. However, as their participation in the program continued, teachers shifted to a more refined and specific view of engineering as a seamless context for the usage of STEM disciplines. This study suggests that there is value in helping teachers reflect on their own conceptions of STEM integration before integrating STEM into their classroom contexts (Ring et al., 2017). Additionally, it points to the importance of professional development facilitators providing time and space for teachers to reflect on their own conceptions. When this is done in collective and collaborative settings, teachers can address and reconcile conflicts between their own understanding and beliefs surrounding STEM learning.

The uniqueness of the engineering design process (EDP) may provide such opportunities for reflecting on ways to seamlessly integrate STEM content knowledge into math and science classroom contexts. Dym et al. (2005) defined engineering design as "a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" (p. 104). The EDP can be defined as a way of thinking to solve problems for a purpose and is a "distinguishing mark of the

engineering profession” (Dym, 1999). The EDP is an interactive decision-making process in which the sciences, mathematics, and engineering are applied to achieve stated goals ( Accreditation Board for Engineering and Technology [ABET], 2013).

Further, previous research demonstrates that full integration of the various STEM disciplines may be difficult to achieve (Wang et al., 2011); however, integrating engineering may be more successful due to engineering design (Bethke Wendell & Rogers, 2013; Estapa & Tank, 2017). In a study using a quasi-experimental design, researchers found significant science content gains among elementary school students who were part of an engineering design-based curriculum. Additionally, students demonstrated motivation and confidence in applying STEM concepts after participating in the curriculum interventions (Bethke Wendell & Rogers, 2013). In another study, classroom teachers, student teachers, and graduate students were able to make connections with STEM content that could be applied to engineering design activities (Estapa & Tank, 2017). MSTs perceived real-world contexts and problems as seamlessly fitting into classroom-based curricula incorporating engineering. However, enactment proved to be challenging, and the researchers suggested a future research focus on how to better support teachers in this domain (Estapa & Tank, 2017). Moreover, these studies underscore that teachers need professional development opportunities to practice integrating STEM disciplines into their pedagogy (Hammack & Ivey, 2019). Training in curriculum design and wider acceptance of materials that support curriculum development are essential to the progress of more successful STEM integration-focused professional development (Guzey et al., 2016). Consequently, our study investigates MSTs’ willingness to enact the EDP into their classrooms after participating in a robotics summer outreach program.

## **Conceptual Framework**

Moore et al. (2014) suggest STEM integration is a combination of some or all the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems. This often occurs by integrating technology and engineering into science and mathematics classes to create learning opportunities for students that are holistic and inter- or cross-disciplinary so that learning becomes connected, focused, meaningful, and relevant to all learners (English, 2016; Smith & Karr-Kidwell, 2000). Examples of high-quality integrated STEM learning experiences may include engaging students in engineering design challenges connected to real-world challenges that are personally relatable, requiring appropriate science and/or mathematics content, engaging students in content using student-centered pedagogies, and promoting communication skills and teamwork (Moore et al., 2014; Ring et al., 2017).

While there is no “best” approach to integrative STEM practices, Bybee (2013) developed a taxonomy for the integration of specific curriculum disciplines, including approaches like coordination across disciplines, complementary overlapping of disciplines, and transdisciplinary course programs. Bybee’s list describes integration on a higher level but does not explain how teachers should go about developing the curriculum that will be used in the classroom.

Moore et al. (2014), attempting to organize the literature on the STEM integration process, developed a framework for checking the quality of STEM education curricula meant to improve STEM integration, teaching, and learning. Six tenets comprise this framework: (a) contains motivating and engaging context, (b) uses engineering design challenges, (c) includes opportunities to learn from failure through redesign, (d) includes math and/or science content, (e) uses student-centered pedagogies, and (f) emphasizes teamwork and communication. There is no clear consensus on what STEM integration is despite the drive to implement STEM in the classroom. However, what is evident is the need to create more opportunities for teachers to

learn how to develop integrative STEM practices, including implementing engineering design in mathematics and science teaching. As such, we used the existing definitions as a conceptual framework to analyze emergent data from the current study that focused on one approach to supporting STEM integration among MSTs in an out-of-school context.

### **Researcher Roles and Commitments**

We are an interdisciplinary group of researchers committed to providing and researching meaningful STEM learning experiences to minoritized populations. Dr. Gaines (PI), with his expertise in Engineering Education, developed the curriculum for and implemented the Bulls-Engineering Youth Experience (Bulls-EYE) program, which serves as the context of the current study. Drs. Vomvoridi-Ivanovic (coPI), Lane (coPI), and Cain (Key Personnel), with respective expertise in Culturally Responsive Mathematics Teaching and Teacher Education, Broadening Participation in STEM and STEM Education, and Qualitative Research Methodologies, led the research and evaluation component of the Bulls-EYE program and the preparation of this manuscript. Additionally, Ms. Ahmad, a doctoral student in mathematics education, and Ms. Willis, a doctoral student in science education, worked as Graduate Assistants and assisted in data collection, analysis, and dissemination of findings. Approval from USF's Institutional Review Board (IRB) was secured prior to conducting the study, and IRB approval remains current.

Along with noting our personal commitments and perspectives to the group, we engaged in critical reflexivity to examine our positionality, biases, and assumptions frequently throughout our inquiry (Cain et al., 2022). These conversations served as rich spaces for meaning making, as we each brought different lenses, experiences, and assumptions with us to the project. For example, many of our team members who were less familiar with extant literature within teacher education were surprised to find that MSTs held deficit perspectives for students; however, in meeting as a team, we were able to discuss established patterns throughout the literature that demonstrated teachers' deficit perspectives surrounding marginalized students' backgrounds and abilities. Later in our analysis, we found that the MSTs who expressed deficit perspectives about the learners' anticipated barriers for implementation of EDP within their classrooms. Additionally, it was particularly disturbing to the entire team when MSTs of color also voiced these deficit views about their students.

Further, we anticipated that MSTs may struggle to implement the knowledge they gained through participating in the Bulls-EYE program given vast differences between the structures of the summer camp and formal classroom contexts. We found this surprising, as student demographics of the youth participating in Bulls-EYE were like those in each MST's school. However, MSTs made a distinction between the Bulls-EYE middle school youth and their own students, positioning their own students as less capable than the middle school youth at Bulls-EYE. While we initially expected that MSTs could struggle in transferring their new skills and knowledge, we did not anticipate that MSTs would feel that Bulls-EYE students were "special" or different from their own students. Ultimately, this limited our ability to draw inferences about effective pedagogical strategies within formal classroom settings, as MSTs reported that their students were not as capable as the Bulls-EYE students—suggesting that they could not try these strategies within their own classrooms.

### **Data Quality Considerations**

In considering our commitments to data quality, we chose to pursue the inclusion of rich rigor, significant contribution, and meaningful coherence (Cain et al., 2022; Tracy, 2010). To complete a thorough and rigorous study, we analyzed our findings for interrater reliability;

upon completion of independent coding, we utilized Dedoose to compare our codes and reached an initial agreement of 92%. After meeting and discussing codes, we had disagreed on, we resolved all discrepancies through negotiation and consensus. Specifically, we discussed each of the excerpts we had applied to different codes to determine where the discrepancies lied. We reached consensus rather seamlessly, since during this process we found that most of the discrepancies were due to having applied the same code to larger or smaller portions of the same excerpt. For example, while one coder had coded this entire excerpt with the code “EDP and math problem solving,” she shared:

Yes, thinking back, I was able to approach some of the early steps...of the engineering design process...with my high schoolers in particular. Because, for example, in teaching word problems, they first have to figure out what the problem is by researching and gathering the data. Okay? I identified what the goal of the problem is. Then, if possible, do some brainstorming. Then implement the best solution that's gonna solve that problem.

Another coder had assigned the same code on part of this excerpt, adding:

...in teaching word problems, they first have to figure out what the problem is by researching and gathering the data. Okay? I identified what the goal of the problem is. Then, if possible, do some brainstorming. Then implement the best solution that's gonna solve that problem.

Therefore, the negotiation was centered around determining which part of the excerpt should be coded using that code. In this case, we determined that the lengthier excerpt should be coded because it specifically addresses both the EDP and the problem-solving process in math, while the second one did not make the connection between the EDP and the problem-solving process apparent.

Our work demonstrates a significant contribution to the field, as literature surrounding teacher knowledge of and barriers to the enactment of the EDP is scarce. Finally, we present a study wherein we analyzed multiple forms of data to provide meaningful coherence to our findings.

## **Case Study Methods**

The current study is part of a larger three-year longitudinal research project funded by the National Science Foundation (NSF#1734878) regarding engineering identity development among middle school youth in a summer outreach program. As part of our larger project, we are exploring the willingness of MSTs who served as mentors in a summer engineering robotics program for middle school to incorporate engineering design in their classrooms. In the current study we sought to address the following research questions:

- What are MSTs’ perceptions of the engineering design process (EDP), and how it applies to their subject matter and classroom context?
- To what extent and in what ways do MSTs incorporate the EDP in their classroom teaching?
- What are perceived challenges to and supports for enacting the EDP in the classroom?

We chose to conduct an in-depth qualitative case study due to the nature of our task in examining an otherwise occurring, unique program (Bulls-EYE), set within a specific period (six weeks of meeting during the summer), and bound by each of our participants sharing a common role (MSTs) that linked their experiences (Flyvbjerg, 2006; Yin, 2009). This method was also appropriate because similar programs, were they to exist, have not yet been previously described within the literature. As such, a descriptive qualitative case study allowed us to embark on this exploratory work (Flyvbjerg).

## **Case Description**

The context of the study is the Bulls-EYE program. Bulls-EYE is a six-week summer STEM program that merges a summer robotics program with a unique mentoring component, including undergraduate engineering students and MSTs who mentor middle school youth of color from the local community. Amongst other things, Bulls-EYE serves as a unique professional development opportunity for in-service MSTs. One objective of Bulls-EYE, and the purpose of this study, is to explore MST mentors' ability and willingness to incorporate aspects of engineering design in their classroom teaching.

This six-week summer program begins with a week-long mentor training that is based on the NSF STARS Alliance Thomas Principles training (Bell-Watkins et al., 2009) and centers on culturally responsive mentoring, that is, mentoring that validates students' various identities and helps them navigate invalidating experiences encountered while simultaneously reinforcing their self-efficacy in STEM (Byars-Winston et al., 2010). Weeks 2-6 contain a curriculum that consists of "Life Skill" lessons and design projects and "Technical Skills." "Life Skills" lessons tie in oral communication skills, such as selling a product to an investor, as well as personal development skills, like developing a personal action plan. The "Technical Skills" portion of the curriculum emphasizes the development of technical concepts essential in engineering. The experience for both mentors and mentees culminates with a rite of passage ceremony at the end that emphasizes sharing individual growth and identity. At the rites of passage ceremony, mentors and mentees express how they have grown personally, professionally, and/or academically during the week. Additionally, mentees and engineering mentors discussed how their participation in the program enhanced their engineering identity, and the teacher mentors shared how they could envision themselves teaching the EDP in culturally responsive ways that may enable students to form engineering identities.

Bulls-EYE implements the novel PHASES Engineering Design Process, an amended version of Ulrich and Eppinger's (2008) seven step design process. "PHASES" stands for "Plan-History-Act-Score-Evaluate-Success." The EDP for Bulls-EYE begins with a simple design process that becomes more complex as students complete their projects. It begins with the steps "Plan-Act-Evaluate" for the first project, which introduces program participants to the hardware and general approach to engineering design. For the second project, the design teams add the step of "History" which encompasses internal and external searches found in more traditional design processes. Program participants search the realm of potential solutions by doing external research and brainstorming internally with the team before acting. For the third project, teams introduce the step of scoring the performance of candidate designs. The "Score" step happens after action and before evaluation. Scoring helps students use engineering tools to inform design decisions before finalizing the design and testing in the evaluation step. Students then reflect on the growth process over the three projects and define the last step of "Success," considering how far they have come. Once program participants complete the third project and the reflection, they have completed the full PHASES design process of "Plan-History-Act-Score-Evaluate-Success." Participating MSTs are expected to draw upon the simpler "Plan-Act-Evaluate" process or the more comprehensive "Plan-History-Act-Score

Evaluate-Success” design process depending on their needs as they return to the classroom after completing the program.

## Participants

Study participants ( $n=8$ ) consisted of two elementary teachers, five middle grades mathematics teachers, and one middle grade science teacher, all within their first five years of teaching, who served as mentors for the entire six-week period of the Bulls-EYE program. Four participants served as MST mentors during Summer of 2018, three during Summer of 2019, and one during both Summers. All MSTs taught in the same public-school district, one of the largest located in the southeastern United States.

## Data Sources

Collecting multiple sources of data to better understand MST experiences is imperative within case study designs (Yin, 2009). We sought qualitative data within this case study due to the exploratory nature of our study design, conducting focus groups in weeks three and six of the summer program and one follow-up individual interview with each MST within the school year following the program. Focus group and interview protocols elicited responses from MSTs about their understanding of the EDP as well as perceived barriers, opportunities, and strategies for incorporating the EDP into their classroom teaching. Focus groups ranged from 60-70 minutes, and interviews ranged from 30-60 minutes and were recorded and transcribed verbatim prior to data analysis.

## Data Analysis

As a team, we established an *a priori* codebook using terms and concepts we gleaned from the literature (Saldaña, 2013). Along with applying these codes deductively, we inductively generated descriptive and *in vivo* codes, which allowed us to use MST’s words and phrases throughout our data analysis. As each of our team members engaged in data analysis, we kept track of newly created codes and met weekly to negotiate the newly generated codes. For example, an *a priori* code is “Time as a Barrier to STEM Integration” which is defined as any reference to difficulties with teaching math or science in a STEM integrated manner in relation to instructional time available (Guzey et al., 2014). An example of a code that emerged inductively is “Lesson Planning as a Barrier to STEM Integration” which is defined as any reference to difficulties with planning STEM integrated mathematics or science lessons. Another example of a code that emerged inductively is “EDP as Problem Solving” which is defined as connections participants make between the Engineering Design Process and problem-solving processes. Upon completion of first- and second-round coding cycles we collapsed our codes into themes based on patterns seen in the literature and across MST responses.

## Findings

Overall, the MSTs were able to define the EDP in ways that mirrored how it was presented in Bulls-EYE. Many MSTs identified the EDP as a problem-solving process applicable to many contexts. Classroom enactment of the EDP was predominantly of an indirect nature, through processes specific to the MSTs’ subject matter (i.e., mathematics problem solving and scientific method), while some MSTs utilized the EDP to solve non-subject-specific classroom problems (e.g., classroom management problems). Direct

enactment of the EDP was limited to STEM projects that were already part of the existing curriculum. Issues relative to instructional resources, lesson planning, time, and student background were the EDP enactment barriers MSTs noted most frequently, while noted supports were all responses to the identified barriers. These findings are described in more detail in what follows.

### **Learning the EDP**

The MSTs came to the program with varied but limited experience relative to engineering and the EDP, and no experience with robotics. All eight MSTs defined the EDP as consisting of the following steps, in this sequence: defining/identifying an existing problem, researching and planning a solution, designing and building, implementing and testing, evaluating, revising and repeating the process as needed. Seven MSTs identified *defining/identifying a problem* as the first step of the EDP and all eight MSTs considered *planning* an important “core idea” of the EDP. The MSTs also conceptualized the EDP as a process of *creating*: “To design, build, or draw a plan or product, in a desire to create a blueprint for the EDP.” After creating the plan, the next step communicated by the MSTs was to *implement* the plan, to act on and test the design process they chose to solve the problem they had identified. Following this process of identifying/defining a problem, planning, creating and implementing a plan, MSTs identified revising the plan and repeating the process as crucial to the EDP.

Several MSTs (n=3) identified the EDP as a problem-solving process that they could apply in contexts outside of engineering and even outside of any specific academic discipline. One MST, for example, described EDP by drawing from his own personal experiences, such as dealing with an inoperable car. He explained that “[the EDP] can be applied to any life problem, [or] any academic problem, that requires you to plan something out, act on it, and evaluate it.” Another MST explained that EDP was like any thinking process that requires a person to complete different steps, saying “that same mindset [of the EDP], that same thinking process [of EDP], could be applied to do your laundry.” These examples are helpful for understanding how in-service teachers may find ways to connect the EDP to students’ everyday lives in the same way they do it for themselves. This capacity to relate the EDP to a variety of life and academic problems provides an opportunity to mitigate perceived barriers to STEM integration in the classroom environment (Moore et al., 2014).

### **Enacting the EDP in the Classroom**

When asked about how they enacted the EDP in mathematics and science teaching, MSTs drew parallels between the EDP and processes specific to their subject matter. One drew parallels between the EDP and the scientific method and identified this as the primary means by which he enacts the EDP in science teaching. He stated, “It’s [EDP] essentially like the scientific method. Ask a question, do research, construct a hypothesis, test it. If it works great. If not, you do another experiment, and maybe change your hypothesis and do it over again.” MSTs who taught mathematics drew parallels between the EDP and the problem-solving process in mathematics and identified this as the primary means by which they enact the EDP in mathematics teaching. One explained:

Yes, thinking back, I was able to approach some of the early steps...of the engineering design process...with my high schoolers in particular. Because, for example, in teaching word problems, they first have to figure out what the problem is by researching and gathering the data. Okay? I identified what the

goal of the problem is. Then, if possible, do some brainstorming. Then implement the best solution that's gonna solve that problem.

However, one MST who taught middle grades mathematics differentiated the EDP from the problem-solving process in mathematics because of the need to “create a prototype and build something” in EDP with the goal to “have some sort of a final product, which is not something you normally do in math.” This MST argued that although the problem-solving process in mathematics follows similar steps and a similar cyclical pattern as the EDP, the solution to a mathematical problem is not a tangible product, which differentiates it from the EDP. Therefore, she described a “house building” geometry project she implements every year where students must build a house with certain parameters and materials provided as the sole means by which she enacts the EDP in her mathematics classroom. This MST also noted she had created this project prior to participating in Bulls-EYE and without the EDP in mind. However, in the follow-up interview, she said that even though her original intent for this project was to engage her students in a “fun” and “hands on” project where students could apply what they learned in math class, she had come to realize that this was an ED project all along. After participating in Bulls-EYE, she was able to identify it as an ED project and, in addition to having her students focus on the mathematics involved, she felt she could also make explicit links with the EDP for her students.

The two elementary MSTs also mentioned using the EDP in their classrooms as part of an already prescribed countywide STEM project they had to do for their district’s “Science Olympics.” The project for kindergarteners, for example, involved building the tallest tower possible using all the materials provided. The “Science Olympics” projects were part of a mandated countywide curriculum which guided students and teachers alike through the EDP. One MST described how she implemented this project into her instruction:

I did talk about the process that engineers go through with planning and stuff, because we had a project...where everybody in the grade level does the exact same thing in the [entire] county. For kindergarten, their thing is who can build the tallest tower, and so we talked about the engineering process. Well, I talked about it, saying, “Okay, engineers they have a blueprint, and what is a blueprint? A blueprint is when you draw a picture of what you’re gonna do” ...and then they drew their blueprint, and then when it was time for them to explore, I let them explore. If their blueprint, when they tried to make it, if they saw they needed to make changes or whatever, they [used] another color and edited their blueprint. That’s why I like the towers, I feel like that was easier to talk about the engineering process, because they planned that. They came with the activity. I was just implementing it.

Finally, two other MSTs described using the EDP in other aspects of their classroom teaching, but not specifically to teach math or science content. One drew a parallel between the EDP and her approach to solving classroom management problems. She explained:

The way that I would say I use that is for classroom management. I identify a problem, I see some solutions, I try to come up with a plan, and then I try to implement it and communicate the plan to my students, and then communicate what works and what doesn’t to myself.

We argue that this quote demonstrates her ability to metaphorically align the EDP process with her classroom management practices, as she shared direct parallels between the two processes.

Similarly, another MST shared that she had adopted the EDP for any type of problem solving—not only for subject specific problems—in her classroom. Any time she and her students faced a classroom problem, they would use a process like the EDP to solve it:

We had something that hung from our board, where the kids put their headphones... It kept falling. At the beginning of the year, it was fine. Then toward the middle, end, it literally fell every day. Then we went through the steps. We were trying to figure out if it was the fabric if it was too many headphones. We did all of that stuff. We basically designed a new way to put it up on the same board. Then after that, we talked about how we went through the steps, [and] I made a big deal about how we went through all of these steps, and we didn't even notice it... Then whenever other problems happened in the classroom, they just thought back to those steps and tried to go through the same process.

With these quotes, each of these two participants demonstrated their understanding and use of the EDP process through describing and unpacking aligned metaphors.

Beyond enacting the EDP indirectly through the scientific method in science or the problem-solving process in math, MSTs' actual enactment of the EDP in teaching their subject matter was limited to non-existent. One middle grades math teacher enacted the EDP through a geometry project she had developed herself prior to participating in Bulls-EYE. Additionally, two elementary teachers leveraged opportunities to incorporate the EDP into their teaching through the annual "Science Olympics" projects that were part of a larger countywide curriculum. Lastly, two MSTs discussed applying the EDP as a general approach to solving classroom management or other classroom problems.

### **Barriers to and Supports for Enacting the EDP**

When asked about the barriers that each MST encountered in planning and enacting the EDP process, participants often discussed barriers and supports concurrently within their responses. We have therefore chosen to combine the two concepts into a single code, though we present each sub-theme separately.

#### ***Perceived Barriers***

The MSTs identified several barriers to incorporating the EDP in teaching their subject matter. The three overlapping challenges all eight MSTs noted most frequently were in relation to instructional resources, lesson planning, and time.

The MSTs pointed to a lack of instructional resources that would support the incorporation of the EDP. Resources were mentioned in different forms, whether comparing the resources MSTs have in their classroom to the ones they worked with during their time in Bulls-EYE, or general material to do a lesson incorporating the EDP. For example, one MST noted, "You can't be expecting that you're gonna have these full, awesome robot kits like we did at Bulls-EYE." Others pointed out that they had resources in their schools, such as lego/robotic kits, but did not know how to include them in an EDP lesson plan. MSTs found it especially difficult to create lesson plans that would integrate the EDP and their content standards together.

Most of the issues connected to lesson planning came from a lack of time to plan lessons. MSTs believed if they were offered lesson plan templates, they would be more successful in incorporating the EDP. One MST suggested the following:

If there is just maybe one, or two, or three lessons, lesson plans that someone can come up with that include a small project, I think that would help out a lot. Because as far as teacher planning, we only have so much time for planning. Incorporating any additional lessons as far as the engineering design [process] can be very time consuming for us.

In addition to the need for increased time for lesson planning, all MSTs agreed that allocating instructional time is also a significant challenge. They believed that incorporating the EDP into the teaching of mathematics or science would take up a lot of instructional time, which from their point of view was already limited. One captured this concern in the following way:

We've got 180 days with the kids, take away—your first week is, a lot of times, a wash. You don't really get into a whole lot of content if you're establishing relations with your student. Take away time for final exam testing, study sessions. You've got your assembly that has been schedule[d] also, for today, and so you're gonna miss four periods.... When it comes down to it, you end up having about 140 days, a lot of times, or less, of genuine instructional time. [And when doing] a large, in-depth assignment, like what we're doing in here, which I think is very beneficial, you're looking at two weeks taken away.

MSTs specifically lamented that the cyclical process of creating, testing, and repeating as many times as needed to develop a viable solution to an engineering design problem is extremely time consuming. One discussed that in her case, where she plans lessons with other teachers as a team, any incorporation of the EDP on her part could take additional time in the classroom which would lead to falling behind in the team's curricular pacing. She explained:

A challenge can be, in my classroom, the team planned together, so we're always teaching along the same thing. Sometimes we go out and teach a different way, but we're really on the same line. If say, I did an engineering design project, and it took me two days longer to teach a concept...I'd be out of sync with the other teachers. That could potentially become a problem where I'd have to rush other content...to catch up with them.

Five MSTs also discussed barriers in relation to their students' backgrounds. These MSTs, all middle grades mathematics teachers, described not being able to incorporate the EDP with their students who had a perceived "lower ability," certain exceptionalities, and a "rough life" at home or in their community. One MST expressed being able to enact the EDP with her gifted students only, as she did not think her "regular" students would have the ability or motivation to apply mathematics through the EDP. She argued that these students "need[ed] to learn basic math skills and do a lot of catching up in math before [she could] even think [about] having them use the EDP." All five MSTs felt that teaching to the standards and building foundational mathematical knowledge was their primary goal for their "lower level" students, and therefore, incorporating the EDP, which was viewed as not contributing to this goal, was of low priority. One MST who taught at an alternative school most frequently noted barriers in relation to her students' backgrounds. Consequently, she resolved:

I would very much like to incorporate the engineering design process in my teaching. However, that will probably not be possible, except maybe for the

geometry students because, in my school, there's a lot of students, [who] not only do they have learning disabilities, which is not preventing me from teaching the engineering [design] process, but a lot of them have missed significant amounts of school over the last year or two, before they get to us. Or they've been in and out of kiddy jail... Their minds, we have to rebuild their minds from scratch in terms of getting them to even care about school. For me, in my situation right now, it's a...crawl before you walk.

The consensus amongst the MSTs who were middle grades math teachers was that for many students, in addition to building foundational mathematics knowledge, it was necessary to also focus on building a growth mindset and student motivation for attending school. These instructional efforts were viewed as preventing them from enacting the EDP in mathematics instruction.

MSTs also identified challenges in relation to school structure, parental support, other outside influences on student learning, and being a novice teacher; however, these challenges were not specific to enacting the EDP but were challenges to teaching mathematics and science in a non-traditional way. For example, two MSTs identified challenges, such as classroom management, that are specific to being a novice teacher, but not specific to incorporating the EDP. Finally, one MST, who was a middle grades science teacher, noted "safety" multiple times as a challenge. As a science teacher, this MST was acutely attuned to safety considerations when performing science experiments and felt that these considerations were also important in engineering design projects.

### *Perceived Supports*

The supports that MSTs discussed were all responses to the identified barriers. MSTs felt that instructional resources such as lesson plans designed to allow for meaningful incorporation of the EDP while explicitly teaching the content standards would help them overcome the identified challenges. Additionally, support from their schools and colleagues would aid them in seamlessly integrating the EDP into their classroom teaching.

Specifically, for challenges related to time and lesson planning, one MST suggested that "gaining more access to resources can shorten that planning process." The MSTs who were middle grades mathematics teachers all agreed that access to mathematics lesson plans that incorporated engineering design, contained assessments, and were linked to the appropriate standards would be a great support in incorporating the EDP in their math classrooms. In other words, MSTs identified access to resources, especially those that are ready for use in the classroom context, as a great support that would aid them in planning instruction that incorporates engineering design, given the limited amount of time available.

In addition to resources, MSTs also identified support from teachers and colleagues as well as the need for professional development focused on assisting teachers with incorporating the EDP in their classroom settings. One MST, who teaches mathematics to students with exceptionalities at an alternative school, stated:

I would like to see some in-service training on how to incorporate... the engineering design process in the various classrooms, specifically classrooms like mine. I would love to do those kinds of things. I just don't always know how to go about it or how to start it. I've tried some different things. Sometimes they work beautifully. Sometimes they really, really, really don't... I would like to learn from someone else's experiences with it... so that I'm not starting from zero every time.

In other words, MSTs wanted professional development opportunities where teachers who teach in unique (e.g., alternative schools) or specific (e.g., middle grades mathematics) instructional contexts could share their experiences with incorporating engineering design in their teaching. This professional development approach could benefit teachers seeking methods of enactment for their local contexts. MSTs further expressed that through their participation in the Bulls-EYE program, they developed a good understanding of engineering design, to apply it to their classroom teaching. However, training in how engineering applies to other subject matters and how the EDP applies to the subject matter each teacher instructs is needed. In this way, an MST suggested, the EDP could be incorporated across content areas in an interdisciplinary unit:

I've mostly seen our design process as it applies to engineering. I would like to see how I can use it more in relation to other content areas or variations of content areas. How does it apply, for example, for an English classroom? 'Cause then, if you can sit there and work out a deal with your English teacher, get some of that cross curricular business going on, that can be excellent. [Or] how can it apply [to the] life sciences?

Finally, MSTs who highlighted difficulties specific to their student populations and backgrounds suggested that administrators prioritize the allocation of resources for handling issues related to student motivation and challenging familial circumstances prior to providing resources for incorporating engineering design into their teaching. Specifically, one MST noted:

[We] definitely [need] student affairs support as far as counseling and social work assistance to help students...address their lower order needs... You'd need a school wide support... so students understand "Hey, we're incorporating this around the whole school, or at least throughout the whole math department, among all the teachers." Then the coach and the department chair of the math department would definitely have to support that. Then the kids would be motivated 'cause then they'd know, okay, if I'm using the engineering design process, then I'm more likely to get something that I want. There's a reason why I'm doing it or at least there's a tangible reason why I'm doing it.

MSTs agreed that "it takes a village" to implement teaching innovations such as the incorporation of the EDP in mathematics and science classrooms. They also suggested that county-wide, school-wide, and department-wide support would be instrumental in creating an environment that is more conducive to successful incorporation of the EDP in their classroom settings.

## **Discussion**

It is encouraging that the eight participating MSTs were able to define the EDP as a process that follows the same steps as those specified in the Bulls-EYE program. In addition to defining the steps of the EDP, MSTs also identified the EDP as a problem-solving process that they could apply in contexts outside engineering and even outside any specific academic discipline, such as classroom management and other classroom problems not specific to the subject matter. In other words, MSTs viewed the EDP as a way of thinking to solve problems for a purpose, which is what Dym (1999) described as a "distinguishing mark of the engineering profession" (p. 146). To our surprise, however, neither of the MSTs noted

collaboration and communication as critical components of EDP, even though both were highlighted in the program. According to Ring et al. (2017) and Moore et al. (2014), high-quality integrated STEM learning experiences are those that, among other things, promote communication skills and teamwork. Nevertheless, through their participation in Bulls-EYE, the MSTs gained hands-on experiences with the EDP that helped build a basic engineering background and content knowledge most mathematics and science teachers lack (Martin et al., 2015). Acquiring this type of relevant content knowledge is a requisite activity for STEM integration (Dare et al., 2018; Guzey et al., 2016; Moore et al., 2014).

It is also encouraging that MSTs drew parallels between the EDP and processes, such as the mathematics problem-solving process and the scientific method, that are central to teaching mathematics and science. This demonstrates their readiness and capacity to enact EDP in their classrooms in ways that mimic processes they already implement to teach their subject matter. Although one MST distinguished the mathematics problem-solving process from the EDP, noting that the creation of a prototype and a tangible product is central to the EDP but absent in mathematics problem-solving, she too acknowledged parallels between the two processes. Identifying similarities and differences between processes that are central in STEM disciplines is important as we increase efforts to foster STEM integration (Kelley & Knowles, 2016).

In addition to articulating the steps in the EDP and identifying it as a problem-solving approach that may apply to many different contexts and parallel processes central to mathematics and science, some MSTs were also able to identify projects in which their students were already using the EDP and expressed that through their participation in Bulls-EYE. They also felt better equipped to facilitate the EDP in their classroom by helping their students make explicit connections between the EDP and activities they engage in through these projects. Unlike MSTs in Estapa and Tank's (2017) study, who also perceived real-world contexts and problems as seamlessly fitting into existing classroom-based curricula incorporating engineering, these MSTs, felt more confident in their ability to enact these curricula and were encouraged to realize that they were enacting the EDP in these projects all along, albeit not explicitly. However, like Estapa and Tank's findings, they found enactment beyond existing classroom-based curricula incorporating engineering to be challenging.

Barriers like those highlighted in the literature (Margot & Kettler, 2019) prevented the MSTs from enacting EDP in mathematics and science teaching in authentic ways. For example, the repetitiveness of the EDP was an identified issue. However, repetitiveness is also present in the problem-solving process in mathematics. Therefore, it is interesting that mathematics teachers drew parallels between the EDP and mathematics problem-solving and did not identify repetitiveness as a barrier in teaching mathematics but as a shortcoming to enacting the EDP in instruction. Future research should explore the extent to which other mathematics and science teachers see repetitiveness as a barrier or strength when integrating EDP into their classrooms as a larger effort toward STEM integration.

Like studies reporting barriers in STEM integration due to teachers' perceptions that their students lack motivation and deficit perspectives about what their students can do and or achieve (Holstein & Keene, 2013), the mathematics MSTs also expressed students lacked motivation for learning mathematics and for schooling in general and lacked prerequisite mathematics knowledge, and they held deficit views of their students' abilities. This indicates that, like MSTs in Guzey et al.'s (2014) study, these MSTs may believe that engineering is just another add-on and overlook the ability for engineering design challenges to teach students content knowledge and the application of content. Further, according to the report by the NRC (2009), among the many benefits of incorporating engineering into the curriculum is boosting student achievement and motivation. The MSTs did not seem to be aware of the potential for increasing both student motivation and achievement through enacting the EDP. MSTs' deficit

perspectives on students' backgrounds and abilities as an identified barrier to enacting the EDP mirrors what is known about traditional (teacher-centered and lecture-focused) practices of teachers who hold deficit perspectives of their students (Manuel, 2019). Those research team members with experience in mathematics and science (teacher) education were not surprised by the fact that MSTs held deficit perspectives on their students' backgrounds and abilities and that these perceptions of their students were identified as a barrier to enacting the EDP. This finding, however, came as a surprise to the rest of our research team who were not familiar with teachers' deficit perspectives on students from marginalized backgrounds being a common theme in the literature. These research team members found it particularly disturbing when MSTs of color voiced these deficit views on their students. Future research could explore interventions specifically targeted to changing teachers' perceptions of the EDP in relation to increasing the motivation and advancing content knowledge of marginalized students.

Our findings highlight a continued need for resources, training, and support for teachers to integrate engineering education into their pedagogy (Hammack & Ivey, 2019; Herro et al., 2019; Roehrig et al., 2012; Wang et al., 2011), including teacher professional development that helps teachers build the engineering background (Martin et al., 2015) needed to implement meaningful engineering design opportunities (Katehi et al., 2009). Teacher professional development should go beyond the technical aspects of the EDP and explicitly attend to twenty-first century skills that are critical components of the process, such as communication and collaboration. Further, our findings support Hammack and Ivey's (2019) recommendation that professional development should provide opportunities for teachers to practice integrating the STEM disciplines into their pedagogy, in this case enacting the EDP in mathematics and science teaching, to facilitate their learning of new knowledge and skills. Professional development should also challenge teachers' deficit perspectives about the students they work with and see that there are larger structural issues that may influence how students engage in traditional classroom environments.

The fact that the EDP's explicit and authentic enactment only occurred through existing engineering design projects that were already part of the curriculum, coupled with MSTs' requests for lesson plans that incorporate the EDP while teaching content standards and following curricular pacing, further highlights the need for curriculum that explicitly links the EDP with content standards and professional development that helps teachers enact these lesson plans. This would remove the notion that engineering-related tasks are an add-on to the existing curriculum, thereby negating issues in relation to time and teaching to the standards. It would also help teachers recognize the potential of engineering design for increasing student motivation while also teaching students both content knowledge and the application of content.

Finally, it is important to leverage teachers' experiences to better make connections with the EDP, such as how it may be used to approach every day and classroom-specific problems. To promote the development of engineering identities both for teachers and their students, it is also important to support teachers in leveraging their students' experiences to make explicit connections with the EDP.

Working on engineering design projects with middle-grade youth helped participating MSTs develop a good understanding of the EDP and allowed them to consider ways in which they could enact the EDP in their classroom teaching. Overall, the EDP seems to offer a promising way to integrate engineering with mathematics and science, especially given the similarities that exist between the EDP, the mathematics problem-solving process, and the scientific method. However, without additional support, such as a district-approved curriculum that includes engineering integration with explicit connections to mathematics and science standards, enacting the EDP in more meaningful ways remains a challenge. Further, to ensure that teachers enact the EDP with all students, not just those identified as advanced or gifted, efforts should focus on challenging teachers' deficit perceptions of marginalized students in

relation to engineering integration and providing counternarratives that illustrate how EDP enactment may increase motivation and advance the content knowledge of marginalized students.

While this lack of opportunities certainly limits our ability to understand the depth behind MSTs' meaning making and perspectives about this process, we argue that ours is but one example of how the EDP process serves as a solid foundation for integrating mathematics and science within middle school classrooms. We agree with Flyvbjerg (2006) that social science scholarship is strengthened by the existence and description of exemplary cases, and as such, have provided what we learned from the Bulls-EYE project through this case study. Further, though case studies are often criticized as not contributing to the larger body of generalizable knowledge, this presentation of an exemplary case allows us to contribute our findings to the development of understanding larger systemic applications (Flyvbjerg, 2006; Yin, 2009) of how the EDP can be used to integrate these fields within middle school classrooms.

### References

- Accreditation Board for Engineering and Technology (ABET). (2013). Student outcomes. *Accreditation criteria for engineering programs*. Author. <http://www.abet.org/eac-criteria-2014-2015/>
- Asghar, A., Ellington, R., Rice, E., Johnson, F., & Prime, G. M. (2012). Supporting STEM education in secondary science contexts. *The Interdisciplinary Journal of Problem-based Learning*, 6(2), 85-125. <https://doi.org/10.7771/1541-5015.1349>
- Bell-Watkins, K., Barnes, T., & Thomas, N. (2009). Developing computing identity as a model or prioritizing dynamic K-12 computing curricular standards. *Journal of Computing Sciences in Colleges*, 24(3), 125-131. <https://doi.org/10.5555/1409873.1409897>
- Bethke Wendell, K., & Rogers, C. (2013). Engineering design-based science, science content performance, and science attitudes in elementary school. *Journal of Engineering Education*, 102(4), 513-540. <https://doi.org/10.1002/jee.20026>
- Byars-Winston, A., Estrada, Y., Howard, C., Davis, D., & Zalapa, J. (2010). Influence of social cognitive and ethnic variables on academic goals of underrepresented students in science and engineering: A multiple-groups analysis. *Journal of Counseling Psychology*, 57(2), 205-218. <https://doi.org/10.1037/a0018608>
- Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA Press. <https://doi.org/10.2505/9781936959259>
- Cain, L. K., Williams, R. E., & Bradshaw, V. (2022). Establishing quality in qualitative research: Trustworthiness, validity, and a lack of consensus. In N. Ivankova (Ed.), *International encyclopedia of education* (pp. 336-350). Elsevier. <https://doi.org/10.1016/b978-0-12-818630-5.11032-2>
- Dare, E. A., Ellis, J. A., & Roehrig, G. H. (2018). Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study. *International Journal of STEM Education*, 5(1), 1-19. <https://doi.org/10.1186/s40594-018-0101-z>
- Douglas, K. A., Rynearson, A., Yoon, S. Y., & Diefes-Dux, H. (2016). Two elementary schools' developing potential for sustainability of engineering education. *International Journal of Technology and Design Education*, 26(3), 309-334. <https://doi.org/10.1007/s10798-015-9313-4>
- Dym, C. (1999). Learning engineering: Design, languages, and experiences. *Journal of Engineering Education*, 88(2), 145-148. <https://doi.org/10.1002/j.2168-9830.1999.tb00425.x>

- Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, 94(1), 103-120. <https://doi.org/10.1002/j.2168-9830.2005.tb00832>
- English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, 3(1), 1-8. <https://doi.org/10.1186/s40594-016-0036-1>
- Estapa, A. T., & Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: A professional development approach centered on an engineering design challenge. *International Journal of STEM Education*, 4(6), 1-16. <https://doi.org/10.1186/s40594-017-0058-3>
- Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, 12(2), 219-245. <https://doi.org/10.1177/1077800405284363>
- Guzey, S. S., Moore, T. J., & Harwell, M. (2016). Building up STEM: An analysis of teacher developed engineering design-based STEM integration curricular materials. *Journal of Pre-College Engineering Education Research (J-PEER)*, 6(1), 1-19. <https://doi.org/10.7771/2157-9288.1129>
- Guzey, S. S., Tank, K., Wang, H.-H., Roehrig, G., & Moore, T. (2014). A high-quality professional development for teachers of grades 3–6 for implementing engineering into classrooms. *School Science and Mathematics*, 114(3), 139-149. <https://doi.org/10.1111/ssm.12061>
- Hammack, R., & Ivey, T. (2017). Examining elementary teachers' engineering self-efficacy and engineering teacher efficacy. *School Science and Mathematics*, 117(1-2), 52-62. <https://doi.org/10.1111/ssm.12205>
- Hammack, R., & Ivey, T. (2019). Elementary teachers' perceptions of K-5 engineering education and perceived barriers to implementation. *Journal of Engineering Education*, 108(4), 503-522. <https://doi.org/10.1002/jee.20289>
- Herro, D., Quigley, C., & Cian, H. (2019). The challenges of STEAM instruction: Lessons from the field. *Action in Teacher Education*, 41(2), 172-190. <https://doi.org/10.1080/01626620.2018.1551159>
- Holstein, K. A., & Keene, K. A. (2013). The complexities and challenges associated with the implementation of a STEM curriculum. *Teacher Education and Practice*, 26(4), 616-637. <https://eric.ed.gov/?id=EJ1044932>
- Hsu, M. C., Purzer, S., & Cardella, M. E. (2011). Elementary teachers' views about teaching design, engineering, and technology. *Journal of Pre-College Engineering Education Research (J-PEER)*, 1(2), 31-39. <https://doi.org/10.5703/1288284314639>
- Institute of Medicine. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. The National Academies Press. <https://doi.org/10.17226/11463>
- Johnson, C. C., Mohr-Schroeder, M. J., & Moore, T. J. (Eds.) (2020). *Handbook of research on STEM education*. Routledge.
- Katehi, L., Pearson, G., & Feder, M. (2009). *Engineering in K-12 education: Understanding the status and improving the prospectus*. National Academies Press. <http://www.nap.edu/catalog/12635.html>
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM education*, 3(1), 1-11. <https://doi.org/10.1186/s40594-016-0046-z>
- King, K. P., & Wiseman, D. L. (2001). Comparing science efficacy beliefs of elementary education majors in integrated and non-integrated teacher education coursework. *Journal of Science Teacher Education*, 12(2), 143-153. <https://doi.org/10.1023/A:1016681823643>
- Manuel, M. (2019). *Examining teacher beliefs and agency upon implementation of culturally*

- responsive pedagogy and the engineering design process* [Doctoral dissertation, Texas Tech University]. <https://ttuir.tdl.org/bitstream/handle/2346/85387/MANUEL-DISSERTATION-2019.pdf?sequence=1>
- Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of Stem Education*, 6(1), 1-16. <https://doi.org/10.1186/s40594-018-0151-2>
- Martin, T., Baker Peacock, S., Ko, P., & Rudolph, J. J. (2015). Changes in teachers' adaptive expertise in an engineering professional development course. *Journal of Pre-College Engineering Education Research (J-PEER)*, 5(2), 35-48. <https://doi.org/10.7771/2157-9288.1050>
- Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In S. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research policy, and practices* (pp. 35-60). Purdue University Press. <http://dx.doi.org/10.2307/j.ctt6wq7bh>
- National Research Council (NRC). (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. The National Academies Press. <https://doi.org/10.17226/12635>
- National Research Council (NRC). (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press. <https://doi.org/10.17226/13165>
- National Academy of Engineering and National Research Council (NAE & NRC). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. The National Academies Press. <https://doi.org/10.17226/18612>
- National Academies of Sciences, Engineering, and Medicine (2020). *Building capacity for teaching engineering in K-12 education*. The National Academies Press. <https://doi.org/10.17226/25612>.
- President's Council of Advisors on Science and Technology (PCAST). (2012). *Report to the President. Engage to excel: Producing one million college graduates with degrees in science, technology, engineering, and mathematics*. Author. [https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final\\_2-25-12.pdf](https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf)
- Reimers, J. E., Farmer, C. L., & Klein-Gardner, S. S. (2015). An introduction to the standards for preparation and professional development for teachers of engineering. *Journal of Pre College Engineering Education Research (J-PEER)*, 5(1), 40-60. <https://doi.org/10.7771/2157-9288.1107>
- Ring, E. A., Dare, E. A., Crotty, E. A., & Roehrig, G. H. (2017). The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *Journal of Science Teacher Education*, 28(5), 444-467. <https://doi.org/10.1080/1046560X.2017.1356671>
- Roehrig, G. H., Moore, T. J., Wang, H.-H., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics*, 112(1), 31-44. <https://doi.org/10.1111/j.1949-8594.2011.00112.x>
- Saldaña, J. (2013). *The coding manual for qualitative researchers* (3<sup>rd</sup> ed.). Sage.
- Silvestri, K. N., McVee, M. B., Jarmark, C. J., Shanahan, L. E., Pytlak-Surdyke, M., & English, K. (2019). Teacher identity in an after-school engineering club: Navigating border crossing in an unfamiliar community of practice. *The Elementary School Journal*, 120(1), 1-31. <https://doi.org/10.1086/704542>
- Smith, J., & Karr-Kidwell, P. (2000). *The interdisciplinary curriculum: A literary review and*

- a manual for administrators and teachers. ERIC. <http://eric.ed.gov/?id=ed443172>
- Tracy, S. J. (2010). Qualitative quality: Eight “big-tent” criteria for excellent qualitative research. *Qualitative Inquiry*, 16(10), 837-851. <https://doi.org/10.1177/1077800410383121>
- Ulrich, K. T., & Eppinger, S. D. (2008). *Product design and development* (4<sup>th</sup> ed.). McGraw-Hill Education Singapore. <https://doi.org/10.1111/j.1948-7169.1992.tb00114.x>
- Vasquez, J., Sneider, C., & Comer, M. (2013). *STEM lesson essentials, grades 3–8: Integrating science, technology, engineering, and mathematics*. Heinemann.
- 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*, 1(2), 1-13. <https://doi.org/10.5703/1288284314636>
- Yin, R. K. (2009). *Case study research: Design and methods* (Vol. 5). Sage.

### Author Note

Dr. Eugenia Vomvoridi-Ivanovic is an associate professor of mathematics education at the University of South Florida. Her research investigates teacher education that is responsive to the funds of knowledge of culturally diverse mathematics teachers and seeks to prepare culturally responsive mathematics teachers who promote equity and social justice in mathematics education. Please direct correspondence to [eugeniav@usf.edu](mailto:eugeniav@usf.edu).

Dr. Tonisha B. Lane is an assistant professor of higher education at Virginia Tech. Dr. Lane studies the experiences and outcomes of underrepresented groups in STEM. Her research also focuses on the representation, retention, and well-being of Black students and professionals in higher education. Please direct correspondence to [tblane@vt.edu](mailto:tblane@vt.edu).

Dr. Leia K. Cain is an assistant professor in the Evaluation, Statistics, and Methodology program at The University of Tennessee, Knoxville. Dr. Cain primarily utilizes qualitative and mixed-methods research. Her areas of expertise include critical methods, narrative methods, interview methods, queer and feminist methods, and the link between researcher identities and ethical reasoning. Please direct correspondence to [leiacain@utk.edu](mailto:leiacain@utk.edu).

Salam Ahmad is a Ph.D. candidate in mathematics education at the University of South Florida. Her research examines notions of equity and accessibility in mathematics curriculum. She is also responsible for training culturally responsive mathematics teachers. Please direct correspondence to [sahmad1@usf.edu](mailto:sahmad1@usf.edu).

Dr. Selene Willis is Deputy Director of The Ingenuity Project, Inc. Her research focuses on equity and curriculum development and placing social justice at the forefront of STEM courses. She is currently the Deputy Director of the Ingenuity Project and Accelerated Math and Science program.

Dr. Jonathan E. Gaines is the inaugural Associate Chair for Inclusive Excellence at the G. W. Woodruff School of Mechanical Engineering. His research interests focus on engineering identity development with special populations of underserved students. In addition, he has research and teaching expertise in data acquisition, engineering design, remote sensing, and robotics.

Copyright 2024: Eugenia Vomvoridi-Ivanovic, Tonisha B. Lane, Leia K. Cain, Salam Ahmad, Selene Willis, Jonathan Gaines, and Nova Southeastern University.

**Article Citation**

Vomvoridi-Ivanovic, E., Lane, T. B., Cain, L. K., Ahmad, S., Willis, S., & Gaines, J. (2024). "That cross-curricular business": The engineering design process in mathematics and science classrooms. *The Qualitative Report*, 29(1), 355-376. <https://doi.org/10.46743/2160-3715/2024.6065>

---