Analysis of Integrated STEM Education: How They Are Reflected in Integrated STEM Curriculum Writing and Classroom Implementation

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Dedication

As I write this section, I am filled with emotion, knowing that I am the first woman in my family to complete a PhD. My ancestors did not have access to education. My grandmother was forced into marriage at the age of thirteen, and my mother faced a similar fate, marrying young and unable to finish middle school.

This degree is more than just academic achievement—it is a symbol of breaking a generational cycle and gaining access to opportunities that were denied to the women before me. I dedicate this PhD to my mother, my grandmother, my ancestors, and all the girls and women around the world who are still deprived of education but hold onto dreams and hopes of changing their destinies. This journey is proof that change is possible, and I hope it inspires others to believe in the power of education to transform lives, just as it has transformed mine.

Abstract

The global urgency to improve STEM education is driven by the environmental and social challenges of the 21st century, which threaten global security and economic stability. Addressing these complex issues requires more than helping students achieve high scores in math and science; it demands educational systems that equip learners with interdisciplinary knowledge and problem-solving skills. In response to these challenges, the United States has implemented extensive STEM education reforms over the past two decades. However, this shift in pedagogical, curricular, and epistemological approaches necessitates a deeper understanding of integrated STEM (I-STEM) education, particularly for educators responsible for translating it into practice. Despite growing efforts, the challenges of defining and operationalizing I-STEM have led to uncertainty among practitioners, highlighting the need for clearer models of I-STEM implementation at both the curricular and classroom levels.

This dissertation seeks to fill key gaps in the literature by analyzing curriculum content and teacher practices. The dissertation focuses specifically on I-STEM integration in elementary science education, providing valuable insights into how I-STEM principles are implemented in both curriculum and instructional practice. Through three interrelated studies, the research offers important findings that contribute to the broader goals of STEM education.

The first study investigates how core I-STEM characteristics are represented in curriculum writing. Using a mixed-methods approach, this study combines quantitative and qualitative analyses to evaluate the extent and quality of I-STEM integration. Quantitative analysis identifies which activities demonstrate core I-STEM features, while qualitative analysis examines how effectively these features are embedded across different activities. The findings provide a comprehensive evaluation of the strengths and limitations of commercially available STEM activities, offering practical recommendations for curriculum developers seeking to enhance I-STEM content.

The second study takes a deeper look into I-STEM implementation at the classroom level through a single-case study of an elementary science teacher. This study explores how the teacher integrated both content and context into her instructional practices, providing insight into how I-STEM principles are applied in real-world classroom settings. The findings from this case study establish a foundation for the third study, expanding the research to explore how these practices vary across multiple classrooms.

The third study employs a multiple-case study approach to investigate how three different elementary science teachers implemented the same I-STEM curriculum. Through cross-case analysis, this study reveals how the integration of context varied among the teachers, demonstrating the diverse ways in which instructional practices can reflect I-STEM principles.

Together, these three studies provide a comprehensive exploration of I-STEM education, offering insights at both the curricular and instructional levels. The progressive nature of the research, along with the use of diverse methodologies and data analysis techniques, contributes to the expansion of STEM education literature. The findings offer valuable guidance for curriculum developers, educators, and policymakers, supporting efforts to improve STEM education by aligning curriculum design with effective classroom practices and promoting interdisciplinary, real-world learning.

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Chapter 1: Introduction

Rationale

STEM (science, technology, engineering, and mathematics) education has gained significant momentum both in the United States and around the world, driven by the growing demand for expertise in STEM fields (National Research Council, 2012). It is widely recognized as essential for addressing the complex challenges of the 21st century (President's Council of Advisors on Science and Technology [PCAST], 2010). Over the past decade, numerous national policy documents in the U.S. have emphasized the need for improvements in K–12 STEM education to prepare students for the future. For example, Rising Above the Gathering Storm (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2007) called for a federal initiative to equip more students with the skills needed for STEM careers. As workforce demands for STEM expertise continue to grow, education systems worldwide are under increasing pressure to prepare students to meet these evolving needs effectively.

To address this growing demand, educators and policymakers are focusing on enhancing students' STEM literacy and equipping them with the skills necessary to engage with real-world problems. Integrated STEM (I-STEM) education, which combines the STEM disciplines in an interdisciplinary approach, has emerged as a promising model for achieving these goals (Moore et al., 2020). It emphasizes using real-world contexts to create authentic learning experiences that resonate with diverse student populations, allowing them to apply disciplinary concepts to solve complex, real-life challenges (National Academy of Sciences [NAS], 2014; National Research Council [NRC], 2011; PCAST, 2010).

In the United States, the Next Generation Science Standards (NGSS) mandate that K–12 science teachers incorporate engineering practices into their teaching (NGSS Lead States, 2013). Thus, K–12 classrooms have particularly focused on engineering as a central component of STEM education (Moore et al., 2015; Roehrig et al., 2021). The inclusion of engineering in the curriculum is seen not only as a response to workforce needs but also as a means of reforming pedagogical strategies. By integrating engineering with science and other STEM disciplines, students engage in learning that is both authentic and relevant to real-world contexts (Bybee, 2013; English, 2016).

However, despite the broad recognition of the importance of improving K–12 STEM education, there is no widely agreed-upon model for what an integrated STEM should look like (Roehrig et al., 2012). Among researchers, policymakers, and educators, there are varying definitions and interpretations of integrated STEM education. This lack of consensus poses challenges for developing teacher preparation programs, designing professional development opportunities, and creating curricular resources that effectively support STEM integration.

Given the challenges in defining and implementing I-STEM education, it is essential to gain a clearer understanding of what I-STEM looks like both at the curricular level and in classroom practices. By analyzing both curriculum content and teacher practices, this dissertation aims to fill significant gaps in the existing literature on STEM integration. These gaps are related to conceptual clarity, curriculum development, teacher preparedness, assessment practices, and the intersection of equity with STEM education.

Understanding these challenges is essential for advancing the field and ensuring that STEM integration effectively supports student learning. Specifically, it explores how I-STEM is represented in elementary science education, offering valuable insights into its implementation at both the curricular and practical levels. The three studies featured in this dissertation contribute important findings about how integrated STEM can be effectively implemented in K–12 classrooms. These findings are critical in supporting the broader goals of the STEM movement, which include improving teacher education, enhancing student engagement with STEM content, and preparing a generation of learners capable of addressing the complex challenges of the modern world.

Organization of the Dissertation

This dissertation follows a three-paper format, with each study presented in separate chapters. The five chapters are organized to ensure a logical flow from the introduction to the synthesis of findings and their implications. Chapters 2, 3, and 4 each focus on one of the three interrelated studies, providing a detailed exploration of integrated STEM (I-STEM) education at both the curricular and classroom levels. Each chapter includes a comprehensive rationale, literature review, methodology, results, and discussion. Chapter 5 synthesizes the findings from all three studies, addressing their collective implications for education, curriculum development, teacher preparation, and future research.

The first study, presented in Chapter 2, investigates how core I-STEM characteristics are reflected in thirty-four distinguished STEM activities published by the National Science Teacher Association (NSTA). This study employs a mixed-method approach, combining both quantitative and qualitative analyses. Quantitatively, identify which activities exhibit the core I-STEM characteristics with a qualitative evaluation of the quality to which these characteristics are integrated across the activities, offering nuanced insights into the strengths and limitations of the curriculum. Through this dual focus, the study provides a comprehensive evaluation of how well commercially available STEM activities reflect I-STEM characteristics. The findings offer valuable guidance for curriculum developers seeking to enhance the effectiveness of I-STEM activities.

The second study, featured in Chapter 3, is an exploratory single case study that delves into how a practicing elementary science teacher implemented STEM integration in her classroom. The focus of this study is to examine how the teacher integrated context and content into her instructional practices. The insights gained from this study serve as the foundation for the third study, expanding the research focus to include multiple classrooms and exploring the variability in I-STEM practices among different educators. This study was presented at the American Society of Engineering Education (ASEE) conference and published in the peer-reviewed conference proceedings (Faruqi et al., 2022).

Building on the findings from the second study, Chapter 4 presents a multiple-case study that investigates how three elementary science teachers implemented the same I-STEM curriculum in their classrooms. This study focuses on understanding how the integration of context varied across the three teachers. Through cross-case analysis, this study reveals how the integration of context varied across the three teachers, offering deeper insights into the different ways in which context integration can be manifested in teaching practices.

Chapter 5 synthesizes the findings from all three studies, offering a comprehensive discussion of the implications for STEM education at both the curricular and classroom levels. The chapter outlines key recommendations for curriculum developers, teacher educators, and policymakers, emphasizing the need for clearer guidelines and frameworks to support integrated STEM education. It also identifies areas for future research, such as exploring how I-STEM practices impact student learning outcomes and investigating the long-term effects of rubric-guided lesson planning on student engagement and performance.

Chapter 2: Examining the Core Characteristics of Integrated STEM Education Reflected in Integrated STEM Activities Published by NSTA

The integrated STEM (I-STEM) reform movement has introduced significant changes in K–12 education worldwide (Blackley & Howell, 2015). This reform emphasizes the integration of engineering and technology into traditional science and mathematics classrooms, aiming to engage students in solving real-world problems (Bryan et al., 2015). However, for the I-STEM movement to progress beyond being a mere slogan (Bybee, 2010), it is crucial that teachers develop a deep understanding of the key features of I-STEM and effective strategies for its implementation. Unfortunately, teachers often face challenges due to a lack of guidance, resources, and professional support necessary for implementing STEM instruction effectively (Gardner & Tillotson, 2019).

The literature highlights several barriers that teachers encounter when applying the I-STEM approach in their classrooms. One major difficulty is the integration of STEM disciplines outside their primary area of expertise, with many teachers struggling to blend these subjects cohesively into their teaching (Couso & Simarro, 2020; Shernoff et al., 2017; Aslam et al., 2023). A particular challenge lies in the integration of engineering, which is a central component of I-STEM reform documents, yet remains a subject area that most teachers have limited knowledge and experience with, making it difficult to incorporate effectively into classroom instruction (Lau & Multani, 2018; Roehrig et al., 2012).

The challenges teachers face in implementing I-STEM underscore the need for high-quality I-STEM curricula that not only provide guidance on instructional practices but also empower teachers to deliver integrated STEM education confidently. I-STEM curricula, therefore, play a pivotal role in bridging the gap between reform intentions and classroom realities. Well-designed curricula can serve as essential tools that provide teachers with structured, practical guidance on incorporating STEM integration into their lessons effectively, enhancing their confidence and competence in delivering I-STEM education (Jagger & Yore, 2012; Aslam et al., 2023). However, this reliance on curricula also raises important questions about the quality and effectiveness of I-STEM activities currently reflected in educational materials. Ensuring that these resources are thoughtfully developed and aligned with the core principles of I-STEM is crucial to overcoming the challenges faced by educators and advancing the success of the I-STEM movement in K–12 education. Therefore, this study aims to examine the characteristics of the integrated STEM activities available for elementary grades. Through this research, the following research questions will be addressed:

- *In what ways do the STEM activities reflect the core characteristics of Integrated STEM within published STEM activities?*

Literature Review

Defining Integrated STEM Education

There is still no universally agreed-upon definition of I-STEM, with various interpretations and implementations leading to inconsistent integration across STEM disciplines (Moore et al., 2020). Over the past two decades, much of the STEM education in schools has involved limited integration, often treating the disciplines as separate entities rather than a cohesive whole (Kelley & Knowles, 2016). Despite this, researchers stress the importance of integrating STEM subjects to reflect the interconnected nature of real-world applications (Moore et al., 2020). Kelley and Knowles (2016) describe I-STEM education as “an approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context, aimed at connecting these subjects to enhance student learning” (p. 3). This perspective emphasizes the need to teach STEM subjects not in isolation but in a manner that highlights their interrelatedness within real-world scenarios. Similarly, Moore, Stohlmann et al. (2014) define integrated STEM education as “an effort to combine some or all of 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” (p. 36). This approach seeks to break down the traditional barriers between STEM subjects, encouraging students to engage in learning experiences that mirror the interdisciplinary nature of STEM careers.

I-STEM Conceptual Framework

Other definitions of integrated STEM education adopt a more holistic approach, emphasizing shifts in pedagogy and curriculum design. Breiner et al. (2012) describe STEM integration as a move away from traditional lecture-based teaching towards a more dynamic approach that includes inquiry and problem-based learning. Integrated STEM curricula are designed to blend science, technology, engineering, and mathematics concepts in ways that mirror the practices of professionals working in STEM fields, providing students with learning experiences that closely resemble real-world applications. Moore et al. (2014) further suggest that science and mathematics serve as key entry points for integrated STEM education, providing opportunities to embed interdisciplinary approaches within these subjects. The inclusion of engineering practices in the Next Generation Science Standards (NGSS Lead States, 2013) underscores the national recognition of STEM integration within K–12 education, particularly within science classrooms. This integration not only enhances the relevance of STEM learning but also aligns classroom instruction with the skills and practices needed in STEM careers, supporting a more cohesive and application-focused education for students (English, 2016; Kennedy & Odell, 2014; Rinke et al., 2016).

Various approaches to STEM education have been proposed, ranging from treating STEM disciplines as separate and unconnected to fully integrating all four disciplines of science, technology, engineering, and mathematics (Bybee, 2013; Fogarty, 1991). While I-STEM education can be modeled and defined in a number of ways; some common elements exist across models. Roehrig and colleagues (2020) presented a framework based on a review of the literature and argued that a quality integrated STEM curriculum includes seven characteristics: (a) focus on real-world problems, (b) centrality of engineering, (c) context integration, (d) content integration, (e) STEM practices, (f) twenty-first-century skills development, and (g) STEM careers awareness (Table 2.1).

Table 2.1: Summary of Characteristics of I-STEM

Tenets of Integrated STEM Framework	Description
Focus on real-world problems	Real-world problems contextualize and motive learning (Kelley & Knowles, 2016; Kloser et al., 2018) and engage learners in applying STEM knowledge in proposing solutions (Monson & Besser, 2015).
Centrality of engineering	Real-world problems in integrated STEM education are addressed through EDC, engaging students in authentic engineering practices to develop solutions to complex problems (Cunningham and Lachapelle, 2014; Moore et al.,

Tenets of Integrated STEM Framework	Description
	2014; Stohlmann et al., 2012). This approach fosters engineering thinking and deepens their understanding across STEM disciplines (NRC, 2012; Moore et al., 2020).
Context integration	Context integration in STEM education uses real-world problems or engineering design challenges to make learning meaningful and relevant (Kelley & Knowles, 2016). This approach connects classroom instruction with real-world applications, preparing students for STEM careers through authentic, purpose-driven activities (Cunningham & Lachapelle, 2014; Moore et al., 2014).
Content integration	Content integration in STEM education blends science, technology, engineering, and mathematics to create cohesive learning experiences (Bybee, 2013; Rennie et al., 2012). This approach fosters robust design solutions, enhancing problem-solving skills and deepening understanding of integrated STEM concepts through iterative and reflective processes (Tank et al., 2019).
STEM practices	A key goal of integrated STEM education is to immerse students in the practices used by professionals in STEM fields, helping them understand the nature of the work and the processes involved (Kelley & Knowles, 2016; Moore et al., 2020; Reynante et al., 2020).
Twenty-first-century skills development	Twenty-first-century skills, such as knowledge construction, real-world problem-solving, creativity, communication, and collaboration, are essential for students to adapt and succeed in the future STEM workforce (Moore, Glancy, et al., 2014; Stehle & Peters-Burton, 2019).
STEM careers awareness	Integrated STEM education immerses students in the authentic work of STEM professionals, offering a deeper understanding of STEM careers by engaging them in real-world skills, processes, and problem-solving strategies (Luo et al., 2021; Ryu et al., 2018).

This framework focuses on engaging students in an engineering design challenge as a means to contextualize learning through real-world scenarios. This view of learning contextualizes student learning of science and provides students with a realistic representation of how STEM knowledge is used beyond K–12 education and centers students' interests and needs. In the following section, these characteristics are unpacked to fully describe I-STEM as used within this study.

Focus on Real-World Problems

Advocates of integrated STEM (I-STEM) education emphasize the importance of using real-world problems as a learning context, arguing that this approach motivates students and gives purpose to STEM learning (Kelley & Knowles, 2016; Monson & Besser, 2015). The focus on real-world contexts is a key element in I-STEM definitions, offering meaningful learning experiences (Kelley & Knowles, 2016; Kloser et al., 2018; Moore et al., 2020). Engaging students with authentic problems helps them apply STEM content and practices in ways that mirror professional work, preparing them to tackle complex challenges beyond the classroom (Breiner et al., 2012; Dare et al., 2018; Brown & Bogiages, 2019).

However, I-STEM activities often focus on male-oriented, technical tasks, which may not engage all students (Gunckel & Tolbert, 2018). Research highlights that girls and students of color are more motivated by activities addressing societal issues, such as sustainability and social justice, rather than traditional gendered tasks (Billington et al., 2013; Leammukda & Roehrig, 2020; Pleasants et al., 2021).

While pure STEM problems build essential cognitive and problem-solving skills, they may lack relevance, leading to student disengagement (Jong et al., 2020; Moore et al., 2020). STEM-relevant problems, on the other hand, bridge theory and practical application, making STEM content more meaningful (English, 2016; Moore et al., 2020). Community-based STEM education further enhances motivation by connecting learning to real-world issues, fostering civic engagement, and promoting social responsibility, particularly in underrepresented communities (Guzey et al., 2016; Roehrig et al., 2021). These approaches highlight the need for diverse and contextually relevant STEM education to promote inclusivity and student engagement.

Centrality of Engineering

Engineering is a central element in most definitions of I-STEM education, most often by framing real-world problems as engineering design challenges (Berland & Steingut, 2016; Mehalik et al., 2008; Moore, Stohlmann et al., 2014; Nathan et al., 2013; Moore et al., 2020). The National Academy of Engineering (NAE, 2009) identifies engineering as "a catalyst for integrated STEM education" (p. 150), highlighting its crucial role in connecting STEM disciplines. Scholars argue that incorporating engineering design is essential for fostering true integration (Bryan et al., 2015; Moore et al., 2014; Sadler et al., 2000). Engaging students in engineering design fosters interdisciplinary learning and problem-solving skills (Berland & Steingut, 2016; NAE & NRC, 2014; NRC, 2012; Pleasants et al., 2021) and enhances students' understanding of scientific concepts through practical application (Apedoe et al., 2008; NAE & NRC, 2012).

In K–12 science classrooms, engineering is often incorporated through engineering design (Brophy et al., 2008; NAE, 2009). The engineering design process is iterative, beginning with problem identification, considering constraints and criteria for desired outcomes, and concluding with refined solutions (NRC, 2010). This process involves testing and modifying solutions based on results, leading to optimal outcomes (NRC, 2012). It is crucial for K–12 students to have opportunities to fully engage in the engineering design process, including cycles of evaluation and redesign, to develop deeper learning and practical skills (Moore, Stohlmann, et al., 2014).

Context Integration

The integration of real-world problems and engineering design challenges in STEM education has been widely recognized as an effective strategy to motivate students and foster their engagement in applying and expanding their STEM knowledge (Lachapelle & Cunningham, 2014; Berland & Steingut, 2016; Monson & Besser, 2015). However, for such activities to be truly effective, there must be a clear and explicit alignment between the context (engineering design challenges or real-world problems) and the specific content-learning objectives they aim to address (Roehrig et al., 2021). A well-structured I-STEM activity ensures that students are not simply participating in hands-on activities for engagement alone. Rather, the engineering or real-world context should be carefully crafted to require the application of relevant STEM principles, pushing students to employ scientific, mathematical, and engineering concepts to develop robust solutions (Roehrig et al., 2021) through evidence-based decisions (Kelley & Knowles, 2016; Kloser et al., 2018; Moore et al., 2020). Without a deliberate and explicit connection between the context of the problem and the learning goals, design tasks can easily devolve into activities resembling crafting or tinkering, driven primarily by trial and error rather than a deep engagement with STEM content (McComas & Burgin, 2020; Moore, Glancy, et al., 2014; Roehrig et al., 2021). In such scenarios, students may become focused on superficial aspects of the task, such as aesthetics or basic functionality, without necessarily engaging with the underlying scientific or mathematical principles intended to be taught. To mitigate these risks, it is critical that STEM activities be designed for students to apply their STEM knowledge in meaningful ways (Lachapelle & Cunningham, 2014).

Content Integration

I-STEM requires the integration of two or more STEM disciplines (Brown & Bogiages, 2019; Kelley & Knowles, 2016). However, more is required than the presence of multiple disciplines, it is important that students understand the connections across the range of content representations and activities within an integrated STEM lesson, (Dare et al., 2018; Tran & Nathan, 2010). I-STEM requires careful planning to ensure that the interconnectedness of the disciplines is clear and coherent, avoiding mere juxtaposition of subjects that can lead to student confusion (Green, 2014). Effective integration necessitates deliberate connections between disciplines, supported by guidance and scaffolding from educators to help students bridge gaps between different fields (NAE and NRC, 2014).

However, the integration of mathematics in STEM education often remains limited, overshadowed by science and technology, which diminishes its role in interdisciplinary contexts (Roehrig et al., 2021). Research indicates a frequent lack of robust mathematical concepts in STEM curricula, leading to insufficient engagement with mathematics (Just & Siller, 2022). There is also a scarcity of research on students' interdisciplinary understanding, particularly in mathematics, underscoring the need for frameworks that connect mathematics more effectively with other STEM disciplines

(Gao et al., 2020). Initiatives to address these gaps include professional development programs aimed at enhancing teachers' skills in integrating mathematics into STEM lessons (Hobbs et al., 2019). Nonetheless, significant challenges persist, such as the need for comprehensive teacher education programs and curricula that emphasize mathematics equally alongside other STEM fields (Evans et al., 2019).

STEM Practices

Disciplinary practices serve as a valuable framework for integrating STEM subjects and linking fields through the shared actions and processes of professionals (English, 2016). These practices reflect the real-world activities of STEM practitioners, such as experimentation, design, data analysis, and problem-solving, making them essential for students to engage with in order to learn deeply and understand the nature of each field (Kelley and Knowles, 2016; Lee et al., 2013). According to expert panels of STEM practitioners and educators, it is crucial for students to shift their focus from simply acquiring content knowledge to engaging in the practices specific to each discipline (NRC, 2012). By emphasizing these practices, students learn not just the content but also how to apply their knowledge in ways that mirror the work of professionals in real-world contexts (Rinke et al., 2016).

Integrated STEM lessons enhance students' ability to apply scientific and mathematical content through explicit use of evidence-based reasoning (Siverling et al., 2017). These lessons require students to justify their design decisions using evidence, scientific principles, and mathematical reasoning. For instance, students may need to justify why an initial design solution should be pursued during the planning phase or defend a tested design solution to a client based on evidence and STEM content (Mathis et al., 2016; Mathis et al., 2018; Roehrig et al., 2021). This approach asks students to make claims about their designs, supported by evidence from iterative testing and reasoning based on scientific and mathematical concepts (Siverling et al., 2019). By encouraging students to critically evaluate their design choices using evidence and STEM principles, educators can help students move beyond surface-level considerations like cost. This approach supports the development of reasoning skills, where students are required to justify their decisions based on scientific and mathematical concepts, such as the structural integrity of materials, the efficiency of a system, or the environmental impact of their designs.

Twenty-First Century Skills

In addition to developing specific STEM practices, I-STEM should be configured to equip students with twenty-first-century skills critical for success in the modern world (Moore, Glancy, et al., 2014; Sias et al., 2017). These skills are broadly categorized into three dimensions: cognitive, interpersonal, and intrapersonal (NRC, 2011). Cognitive skills include judgment and decision-making, systems analysis and evaluation, and abstract reasoning. These skills are vital for problem-solving and critical thinking, enabling students to navigate complex challenges effectively (Brown, 2018).

Interpersonal skills, another crucial dimension, involve active listening, effective communication (both verbal and non-verbal), collaboration, and cooperative skills. These skills also extend to building trust, fostering creativity, understanding and respecting differences, valuing diverse perspectives, and positively influencing others. Mastery of these skills is essential for students to function effectively in today's interconnected world, where teamwork and communication are paramount (Stehle & Peters-Burton, 2019).

Integrating real-world problems and engineering design challenges in STEM education requires students to engage deeply in critical thinking and creativity (Kloser et al., 2018; Moore et al., 2020). The nature of these challenges, which are often complex and ill-defined, compels students to draw on their STEM content knowledge as well as their personal experiences to devise solutions. The engineering design process, by its very nature, supports creativity and critical thinking through its open-ended approach, which encourages exploration of multiple pathways and recognizes that there is no single correct solution (Stretch & Roehrig, 2021; Petroski, 2016; Simpson et al., 2018). This process fosters an environment where students can experiment, test ideas, and iterate on their designs, leading to innovative and transformative outcomes.

Given the interdisciplinary and collaborative nature of engineering, it is crucial for students to develop strong teamwork skills (Brown, 2018). Working in teams allows students to enhance their collaboration abilities, which are essential for integrating diverse perspectives and synthesizing different understandings of complex problems (Riel et al., 2012; Rinke et al., 2016; Thibaut et al., 2018). Collaboration plays a pivotal role in the engineering design process, as it facilitates the co-construction of knowledge and the development of well-rounded design solutions that benefit from the input of multiple viewpoints (Wendell et al., 2017).

STEM Career Awareness

To foster future participation in STEM careers, I-STEM should immerse students in the realities of STEM professions, engaging them in authentic activities that reflect the work of professionals in these fields (Jahn & Myers, 2014; Luo et al., 2021). This approach helps students experience firsthand the skills and practices used in STEM, bridging the gap between classroom learning and real-world applications (Kitchen et al., 2018; Ryu et al., 2018). Research suggests that students' interest, attitude, and sense of identity in STEM are stronger predictors of their continued engagement in these fields than academic performance alone (Avraamidou, 2020; Rodriguez et al., 2017; Tai et al., 2006).

However, a notable challenge remains: even among students who excel in STEM subjects, many do not see themselves pursuing STEM careers, particularly those from historically underrepresented groups such as women and minorities (Capobianco et al., 2011; Rodriguez et al., 2017). I-STEM education plays a crucial role in not only introducing students to various career pathways but also emphasizing the diversity within STEM fields to positively shape students' perceptions of these careers (Tai et al., 2006). Connecting STEM learning to students' personal experiences and cultural backgrounds is particularly important for fostering strong STEM identities, especially among diverse student populations (Ryu et al., 2018; Carlone et al., 2014; Sias et al., 2017). When students see how STEM concepts relate to their own lives and communities, they are more likely to develop a sense of belonging in these fields. This connection can transform their perception of STEM from an abstract academic pursuit into a tangible vision of themselves as future contributors in these careers.

I-STEM Pedagogy: Emphasizing Learner-Centeredness

I-STEM education relies on student-centered pedagogies, where students have agency in their learning process, especially during the engineering design process. This approach empowers students to explore multiple solution pathways, fostering knowledge construction through their questions and ideas (Berland & Steingut, 2016; Johnson et al., 2016; Saito et al., 2015). Learner-centered I-STEM emphasizes inquiry, problem-solving, and project-based strategies, moving beyond traditional teaching to make students active participants in their education, with teachers facilitating rather than directing the learning (Koehler et al., 2015).

In this learner-centered approach, engineering design challenges should be structured to promote epistemic agency, positioning students as active contributors rather than passive recipients (Koehler et al., 2015). This involves allowing students to shape the knowledge-building work within their classroom community, aligning with the vision of the Framework for K–12 Science Education, which emphasizes student engagement in STEM practices (NRC, 2012; Miller et al., 2018). By giving students an active role, I-STEM fosters a deeper connection between theoretical content and practical application, ensuring meaningful and relevant learning experiences.

Methodology

A sequential explanatory mixed methods design was employed to analyze the characteristics of published I-STEM activities. This approach involves the systematic collection, analysis, and integration of both quantitative and qualitative data throughout the research process (Creswell, 2005; Teddlie & Tashakkori, 2009). The rationale for choosing this design was rooted in the understanding that neither quantitative nor qualitative methods alone could fully capture the complexity and integrated nature of integrated STEM activities (Johnson et al., 2007). When properly combined, these methods complement each other, providing a more comprehensive understanding of the research problem (Creswell & Plano Clark, 2011; Green et al., 1989; Johnson & Turner, 2003; Tashakkori & Teddlie, 1998).

Within this study, the quantitative data provided a general overview of whether the STEM activities embodied the characteristics of integrated STEM. The qualitative data offered deeper insights into the quality and nature of integration within those activities, allowing for a more nuanced understanding of the integrated STEM approach. The integration of these two phases is reflected in the results and discussion sections, ensuring that the analysis met the mixed methods evaluation criteria outlined by Creswell and Plano Clark (2011) which emphasize the importance of explicitly combining quantitative and qualitative databases in the interpretation of results (p. 269).

Data Sources

Available teacher resources for integrated STEM in the elementary grades were searched for online. The online search criteria included the terms integrated STEM resources, lesson plans, and curriculum resources for elementary grades. Lessons that satisfied search parameters were then further scrutinized to ensure they were ‘vetted,’ either recommended by professional science teacher organizations or produced by trustworthy organizations with knowledge of integrated STEM education (i.e., governmental, university, or scientific agencies). After exploring numerous resources, including TeachEngineering, NASA for Educators, PBS Learning Media, Code.org, and Smithsonian Science Education Center, we selected the curricular resource for elementary science teachers published by NSTA Press in May 2016, which specifically focuses on I-STEM. This resource was chosen because, unlike other options that primarily emphasized science exploration, it offered a comprehensive series of STEM-based activities tailored for elementary teachers. NSTA Press, a reputable and trusted organization in science education, provides a curriculum that not only integrates multiple STEM disciplines but also emphasizes hands-on, inquiry-based learning that aligns with real-world applications. The 34 activities are organized into grade-level bands, ensuring that the content is developmentally appropriate and aligned with the learning needs of students at different stages. For a detailed summary of the activities see Table 2.2.

Table 2.2: Grade Pre-K–5

Grade Band	Activities	Activity Overview
Pre-K–2	1a: Grades K–2: Magnificent Things Solve Problems (Royce, 2016)	In this activity, students engage in the EDP by exploring how different designs serve specific purposes. After comparing snow shovels and digging shovels to understand how design impacts functionality, they read The Most Magnificent Thing to learn about the iterative nature of designing and improving inventions. Working in groups, students tackle one of two hands-on challenges: building a bridge for a toy car or creating a container to keep marbles or balls secure as a vehicle moves on a ramp. They sketch, test, and revise their designs.
3–5	1b: STEM's Own Amazing Race (Royce, 2016)	In this activity, students engage in an engineering design challenge to build a boat powered by wind from blowing through a straw, aiming to cross a water channel as quickly as possible. The lesson begins with the story Papa's Mechanical Fish, sparking discussions on iterative design and the importance of modifying prototypes. Working in teams, students brainstorm, sketch, and build their boats using specific materials that meet design criteria and constraints. Through multiple testing and refining cycles, they optimize their boats for speed and performance. After racing their designs, students

Grade Band	Activities	Activity Overview
		reflect on successful features, areas for improvement.
Pre-K–2	2: Testing Flying Machines (Morgan at el., 2016)	In this activity, students explore flight and friction principles by building model hovercrafts inspired by the book Captain Arsenio: Inventions and (Mis) Adventures in Flight. After discussing the importance of documenting designs, students use materials like CDs, balloons, and bottle caps to construct their hovercrafts. They test their designs, observing how air reduces friction and helps the hovercraft move. After watching a video on real-life hovercraft challenges, students modify their designs to carry a marshmallow (representing Captain Arsenio) while considering forces such as friction, gravity, and air resistance.
Pre-K–2	3: Gimme an *E*! (Hoisington & Winokur, 2016)	This activity introduces young learners to engineering concepts through constructive play, allowing children to design and build structures with various materials. Through hands-on exploration, they learn about stability, strength, and the effects of forces. Students were given different materials to build towers and animal enclosures. The activity integrates literacy and math as children document their designs, use descriptive vocabulary, and measure their creations.
Pre-K–2	4: THE EDP-5E (Lottero-Perdue, Bolotin et al., 2016)	This activity integrates the EDP into the 5E framework to teach preschool and kindergarten students about engineering. Instead of the traditional “Exploration” phase, students engage in hands-on problem-solving through design. The lesson begins with a reading of Iggy Peck, Architect, introducing building concepts. Students then design and build towers and houses to protect a toy crab from an alligator, considering specific criteria and

Grade Band	Activities	Activity Overview
		constraints. They brainstorm, plan, create, test, and improve their structures while reflecting on their designs.
Pre-K–2	5: Can a Student Really Do What Engineers Do? (Brown et al., 2016)	In this activity, students explored material properties and their ability to filter soil from water. This began with an engaging activity on filters, followed by an exploration where students tested various materials. During the explanation phase, they analyzed results and identified which materials were most effective. They then elaborated by designing and building their own water filters. They concluded with an evaluation of their designs and a discussion on real-world water treatment, emphasizing engineering's impact on society and the environment.
Pre-K–2	6: Catch Me if You Can! (Lott et al., 2016)	In this activity, students are tasked with designing and building a trap to catch the gingerbread man from the classic story "The Gingerbread Man." By applying creativity, problem-solving, and engineering skills, students explore how to construct an effective trap using available materials while considering factors such as structure, stability, and functionality.
Pre-K–2	7: Inviting Engineering into the Science Lab (Westfall, 2016)	In this activity, students participated in a design challenge by creating a homemade freezer to turn juice into ice pops. They explored different materials, constructed their designs, and then tested the effectiveness of their freezers. Afterward, they compared their results with other groups and analyzed the success of their designs.
Pre-K–2	8: Integrating Design (Ashbrook & Nellor, 2016)	This activity integrates engineering design into early childhood classroom. This activity involves designing a system to transport water using PVC pipes and fittings. Teachers guide children through

Grade Band	Activities	Activity Overview
		the design process, encouraging exploration, testing, and refining of solutions. The lesson emphasizes the value of learning from failed attempts, helping children to adjust and improve their designs. By working with familiar materials both indoors and outdoors.
Pre-K–2	9: Elephant Trunks and Dolphin Tails (Hefty, 2016)	In this activity, students learn how engineers help animals by designing a prosthetic trunk for a rescued elephant, inspired by real-world examples like penguin wetsuits and dolphin prosthetics. Students work in teams to research, brainstorm, and build prototypes with various materials. They improved their designs based on the data they collected.
Pre-K–2	10a: Engineering Adaptations: Moving Pigs (Gatling & Vaughn, 2016)	In this lesson, students learn force and motion concepts through an engineering design challenge where they create an escape route for "pigs" stranded on an island. Using materials like cove molding, clay, cotton swabs, and blocks, students collaborate in groups to brainstorm, design, build, and test models to safely transport the pigs across a river. Through iterative testing, discussion, and comparison, they optimize their solutions.
Pre-K–2	10b: Engineering Adaptations: Point Pollution in a Watershed (Gatling & Vaughn, 2016)	In this activity, students explore watersheds and pollution through an engineering design challenge. Students begin by building a watershed model to observe how pollution moves through it, learning about soil erosion and runoff. They research solutions and brainstorm methods to contain pollution with materials like sponges, sand, and foil. After designing, building, and testing their models, students revise their designs based on results.
Pre-K–2	11: Sailing Into the Digital Era	In this activity, students used iPads to transform their traditional STEM journals into digital e-books while

Grade Band	Activities	Activity Overview
	(Bellavance & Truchon, 2016)	learning about wind and sail design. Students documented their sail design process, tested their models using a fan-powered track, and recorded observations through photos, videos, and audio. They improved their designs based on the data collected.
Pre-K–2	12: Inventing Mystery Machines (Counsell et al., 2016)	The activity introduces students to physics concepts like motion and force. Students explored different shapes and wheels, investigating the effects of surfaces on motion using office chairs, testing inclined ramps with various objects, and building mystery machines with wheels.
Pre-K–2	13: Am I Really Teaching Engineering to Elementary Students? (McCullar, 2016)	In this activity, students were tasked with designing a windmill capable of spinning and lifting a cup of washers using a string. They explored various engineering fields through centers, with a focus on environmental engineering. Using the EDP, students identified problems, planned solutions, tested designs, and made improvements to create sails and windmills.
Pre-K–2	14: The STEM of Inquiry (Ashbrook, 2016)	In this activity, students are challenged to design a tool to transport a heavy object without directly carrying it. The lesson begins with students examining the object's attributes using their senses and measurements. Working in small groups, they brainstorm, draw, and build carriers using various materials. Throughout the process, students engage in critical thinking, considering material properties and redesigning as needed.
Pre-K–2	15: Printing the Playground (Wendt & Wendt, 2016)	In this activity students were tasked to design a new playground for their school using 3-D printing technology. The activity began with a request from the principal, engaging students in solving a real-

Grade Band	Activities	Activity Overview
		world problem. They brainstormed ideas, sketched their designs, and considered factors like material choice, size, and functionality. During the exploration phase, students used manipulatives to create models, enhancing their understanding of geometric shapes and structures and they used the SketchUp software, to convert their design into a 3-D printed model.
Pre-K–2	16: A House for Chase the Dog (Marrero et al., 2016)	In this activity, students engaged in the EDP to explore material properties by designing a roof for a model doghouse to protect a dog named Chase from rain. Using the 5E model, the lesson began with a discussion on how roofs protect against the elements. Students were provided with materials like wax paper, cardboard, aluminum foil, and cloth, and tested them for water resistance by simulating rain on a milk carton doghouse. They recorded predictions, observations, and explanations on a chart, using evidence from their tests to decide which material was best for keeping the doghouse dry.
Pre-K–2	17: Measuring Success (Zissman, 2016)	In this activity, students engaged in engineering design challenge to create tools to measure the length, width, or depth of a local river. After reviewing maps and measurement concepts, students engaged in ask, imagine, plan, create, and improve steps. They brainstormed ideas, constructed their tools using everyday materials, and tested them during a field trip to the river.
3–5	18: Think It, Design It, Build It, Test It, Refine It (Ehlers & Coughlin, 2016)	In this activity, students explored water filtration by designing and building their own filtration systems. After studying water properties, pollution, and filtration concepts, students worked in pairs to brainstorm, sketch, and construct water filters using materials like water bottles, coffee filters, charcoal,

Grade Band	Activities	Activity Overview
		and cotton. They tested their filters using "polluted" water, assessing success based on criteria such as water clarity, pH, and volume. Students reflected on their designs, made improvements, and discussed how their filtration systems worked, reinforcing their understanding of water filtration.
3–5	19: Community-Based Engineering (Dalvi & Wendell, 2016)	This activity engages students in solving real-world problems within their school environment through engineering. Students tackled the challenge of designing a water transport system for garden beds without easy water access. students first identifying the problem, brainstorming solutions, constructing prototypes, and refining their designs based on feedback. They learned about science and math concepts such as pulleys, water needs for plants, and measurements, while collaborating with peers.
3–5	20: Engineer It, Learn It (Lachapelle et al., 2016)	This activity engages students in designing parachutes for spacecraft landing on a planet with a thin atmosphere and allowing students to explore key engineering and scientific practices. Students begin by asking questions about parachutes and their design constraints, then develop models and test variables like canopy material, size, and suspension line length. They analyze data from their tests, argue from evidence, and refine their designs based on observations.
3–5	21: Designing a Sound-Reducing Wall (Erk et al., 2016)	In this activity, students worked as acoustic engineers to design, build, and test sound-reducing walls. Using a shoebox model divided into a "loud" and "quiet" room, students explored how different materials absorb or reflect sound. They selected materials like foam, cotton balls, and plastic sheets, which were placed into a pocket to construct their walls. Teams then tested their walls by measuring

Grade Band	Activities	Activity Overview
		sound levels with a sound meter app. After discussing results and understanding which materials worked best, students reflected on their designs and how they could be improved.
3–5	22: Blade Structure and Wind Turbine Function (Lottero-Perdue, De Luigi, & Goetzinger, 2016)	In this activity, students explored how the structure of wind turbine blades affects their function, specifically voltage output. Students first conducted experiments to test variables like blade shape, angle, number, and width. After sharing their findings, they engaged in an engineering design challenge to create the most efficient turbine blades using what they learned. The students worked through the EDP, testing and improving their designs.
3–5	23: You and Your Students as Green Engineers (Hegedus & Carlone, 2016)	This activity engages students in a design challenge to design and improve solar ovens. Through a multidisciplinary approach involving literacy, science, and mathematics, students explored environmental issues and green engineering principles. They tested materials for insulation, analyzed their environmental impact, and used these insights to design and improve their solar ovens.
3–5	24: Smashing Milk Cartons (Monson & Besser, 2016)	This activity engages students in a challenge that involves designing a machine to crush milk cartons, using the engineering design process (EDP). After exploring the environmental impact of waste and brainstorming potential solutions, the students defined the problem and worked in small groups to design, test, and improve their prototypes. Their final design was a simple system using a block of wood and a pan to crush the cartons.
3–5	25: Creating a Prosthetic Hand (Cook et al., 2016)	This activity engages students in designing and building a functional prosthetic hand using 3D printing technology. Students worked in teams to

Grade Band	Activities	Activity Overview
		understand the challenges faced by someone with one hand and researched prosthetics and anatomy. They created blueprints using Tinkercad, built prototypes, and refined their designs with feedback from peers and experts.
3–5	26: Gliding Into Understanding (Brown, 2016)	This activity engages students in scientific exploration by investigating paper airplane flight. Using the 5E instructional model, students design, test, and analyze different paper airplane styles (dart, glider, normal) to explore how variables like design affect flight distance. Students learn about t forces, motion, and conducting controlled experiments.
3–5	27: A System of Systems (Peterson, 2016)	This activity engages students in understanding and exploring the interconnected systems of their environmentally friendly school. students investigated systems like electrical, HVAC, and structural components with the help of experts such as architects and engineers. They learned about the systems' parts, functions, and interdependencies and learned how to conduct the research.
3–5	28: Blasting Off with Engineering (Dare et al., 2016)	This activity engages students in designing and testing foam rockets as part of an integrated engineering and physical science activity. Students followed the engineering design process, testing variables like rocket mass, launch angle, and fin design to improve their rockets' performance.
3–5	29: Scampering Into Engineering! (Flannagan & Sawyer, 2016)	This activity engages students in designing wind-powered vehicles. Students used simple materials to build cars that could move using air power and they designed, tested, and redesigned their vehicles, and improved their designs. Through hands-on experimentation, students explored concepts like

Grade Band	Activities	Activity Overview
		friction and air resistance, force and motion while collaborating and sharing their ideas.
3–5	30: Wacky Weather (Sabarre & Gulino, 2016)	This activity engages students in understanding severe weather through the lens of engineering design. Students learn about weather phenomena and tools, research types of severe weather, and apply the engineering design process to create structures that can withstand storms such as tornadoes, hurricanes, and thunderstorms. Using recycled materials, students work in teams to build, test, and modify their designs while applying math and science concepts. The activity emphasizes collaboration, creativity, and problem-solving, culminating in a hands-on testing phase using tools like leaf blowers and water hoses to simulate severe weather. Students reflect on their designs and share their findings with the class, enhancing both their understanding of severe weather and their engineering skills.
3–5	31: Straw Rockets Are Out of This World (Gillman, 2016)	This activity engages students in designing, building, and testing straw rockets to explore key STEM concepts. Students learn about rocket history, Newton's third law of motion, and how forces impact rocket flight. They build straw rockets, manipulate variables such as rocket length, fin shape, and nose cone size, and test their designs at different launch angles to see which travels the farthest. The activity promotes data collection, analysis, and redesign based on performance, fostering problem-solving, collaboration, and an understanding of cause and effect.
3–5	32: Nature as Inspiration (Tank et al., 2016)	This activity engages students in engineering design challenge, in which they were tasked with designing water collection and storage devices inspired by plant adaptations for families in Popa Island,

Grade Band	Activities	Activity Overview
		Panama. Students learned about biomimicry and how nature can inspire engineering solutions by studying different plant adaptations. They worked in groups to plan, create, and test their designs, using science and math concepts such as volume, surface area, and plant structures. Students conducted tests, gathered data, and engaged in a redesign phase to improve their solutions.
3–5	33: The Tightrope Challenge (Burton, 2016)	This activity engages students in an open-ended robotics engineering task, aimed at fostering innovation, problem-solving, and growth mindsets. Using Lego Mindstorms, students were tasked with designing and building a vehicle to traverse a rope, with the more advanced goal of retrieving and dropping a plastic ball at designated points. The challenge required students to engage in the engineering design process, which included defining the problem, researching, designing, building, testing, and improving their models.
3–5	34: Modeling Water Filtration (Parks, 2016)	This activity engages students in designing, building, and testing water filters while working within given constraints such as material availability, cost, and filtration time. Through collaboration and brainstorming, students explore different approaches to creating effective filters. They compare their results, analyze the performance of various designs, and explain which type of water filter best meets the specified requirements based on the materials used, overall cost, and the time it takes to filter the water.

Data Analysis

Analysis of the integrated STEM activities used content analysis, which is described as “a research technique for making replicable and valid inferences from texts to the contexts of their use” (Krippendorff, 2018, p.18). Content analysis was guided by a rubric based on critical characteristics of integrated STEM.

Rubric Development

The development of the rubric for analyzing integrated STEM activities published by NSTA Press was grounded in the Roehrig et al. (2021) framework. The process began with drafting a preliminary version of the rubric, which was structured around the seven characteristics of the Roehrig et al. framework. For each characteristic, sub-codes were developed (as detailed in Table 2.3) to capture specific elements of these characteristics. The rubric was designed to score the presence or absence of these elements in the curriculum.

The draft rubric was piloted by two researchers using two I-STEM activities from the NSTA publication. This pilot phase was crucial for refining the rubric’s purpose, enhancing the clarity of category descriptions, and improving its overall usability. Feedback from the pilot informed several key revisions, including clarifying definitions and ensuring the rubric accurately captured the intended aspects of integrated STEM education. One significant enhancement made during this revision process was the inclusion of criteria to evaluate whether lessons were student-centered or teacher-centered. This addition was essential for assessing the pedagogical approach of the lessons, as student-centered learning is a critical component of effective STEM education. By incorporating this dimension, the rubric was better equipped to distinguish between lessons that actively engage students in the learning process and those that are more directive and teacher-led.

After finalizing the rubric based on the integrated framework, a Google form was created to assess each activity individually and scored independently by two team members (the author and the grad student) using the refined rubric. Researchers then came together and compared their coding. Any disagreements were discussed and resolved. This process also resulted in the refinement of each category of the rubric.

For the qualitative analysis, a deductive approach was employed. The author applied a set of established codes to the activities, with the goal of identifying and assessing the quality indicators associated with each code. By applying these codes across the thirty-four activities, the author sought to not only identify whether these characteristics were present but also to evaluate their quality.

The qualitative analysis delved deeper into how each activity implemented these characteristics. For example, it examined whether activities that included real-world problems did so in a meaningful and engaging way, or whether activities that promote student-centered learning allowed for genuine autonomy and decision-making by the students. This comprehensive approach allowed the study to evaluate not just the frequency of the characteristics but also the quality presented in the STEM curriculum.

Table 2.3: Overview of Rubric Categories

Code Name	Sub Code	Code Descriptions
Real-World Problem	Pure STEM	The activities presented a real-world problem that is fully aligned with science, technology, engineering, and mathematics.
	Non-STEM	The activities presented a real-world problem that is grounded in political, ethical, and other non-STEM disciplines.

Code Name	Sub Code	Code Descriptions
	STEM relevant	The activities presented a real-world problem identified in each of the STEM fields, and the problem has many dimensions that are aligned with non-STEM fields.
	Connection to the community, culture, language, and lives	The activities focused on the community-based problem and addressed students' lived experiences, culture, and language.
Engineering Design Challenge	Problem and background	The activities provided opportunities for students to find a solution, including researching the problem, participating in learning activities to gain background knowledge, and identifying criteria and constraints.
	Plan and implementation	The activities engage students in developing and implementing a plan for a design solution.
	Test and evaluate	The activities allow students to generate a testable hypothesis/question and design experiments to evaluate, data collection, and analysis for the redesign.
Context Integration	Activities included the client to align learning goals	The activities include a client and aligning the EDC with learning goals through the client.
	EDC aligning with learning goals without including a client	The activities allow the EDC alignment with the learning goals.

Code Name	Sub Code	Code Descriptions
Content Integration	S & E	Science and engineering content presented in the activity
	S, E, & M	Science, Engineering, and Math content was presented in the activity.
	S & M	Science and Math present
	E & M	Engineering and Math present.
	Non-STEM discipline	Other than STEM, art, literacy, etc
21-Century Skills	Creativity	The activities provide opportunities for students to engage in multiple possible solutions.
	Communication-Related to Engineering	The activities provide opportunities for students to communicate like STEM professionals, including communication through oral, written, drawings, plans, and schematics.
	Collaboration	The activities provide opportunities for students to work together towards a common goal or project and participate in collaborative groups in a variety of roles.
	Critical Thinking	The activities provide opportunities for students to engage in interpretation, analysis, reasoning, and problem-solving

Code Name	Sub Code	Code Descriptions
STEM Practices	Asking questions (for science) and defining problems (for engineering)	Opportunities for students to ask questions and use the information in design
	Developing and using models	Opportunities for constructing models to represent ideas, explanations, and design solutions
	Planning and carrying out investigations	Opportunities for planning and carrying out investigations to answer questions or test solutions to problems
	Analyzing and interpreting data	Opportunities to analyze data: data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others through graphical interpretation, visualization, and statistical analysis.
	Using mathematics and computational thinking	Opportunities for representing variables and their relationships. Engage in constructing simulations, statistically analyzing data, and recognizing, expressing, and applying quantitative relationships.
	Constructing explanations (for science) and designing solutions (for engineering)	Opportunities for students to engage in constructing explanations to design solutions
	Engaging in argument from evidence	Opportunities to engage in evidence-based reasoning
	Obtaining, evaluating, and communicating information	Opportunities for students to engage in communicating the ideas and methods

Code Name	Sub Code	Code Descriptions
STEM Career Awareness	Mention of STEM careers	The activities mention STEM professionals (like engineers and scientists)
	Gender	The activities mention different gender in the STEM profession (women and non-binary).
Student-Centered		Students have agency in research and design decisions.

Results and Discussion

The results of this study are presented through a combined approach of quantitative and qualitative findings, offering a comprehensive understanding of how integrated STEM characteristics are represented in the activities. The quantitative results focus on the frequency of core STEM characteristics: real-world problems, engineering, context integration, content Integration, STEM Practices, 21st-century skills, and STEM careers across thirty-four activities, providing a clear numerical assessment of whether these elements are present. In parallel, the qualitative findings delve deeper into the depth and quality of the integration, examining how these characteristics are implemented in practice. This integrated approach allows for a thorough evaluation, highlighting the prevalence of STEM characteristics and the richness and quality of their implementation within the activities.

Each activity was evaluated against the criteria for high-quality I-STEM education, as outlined in Table 2.2, which identifies the presence of key I-STEM characteristics in each activity. This evaluation also assessed the student-centered nature of the activities, determining whether they facilitated active student engagement through exploration, decision-making, and collaboration, in contrast to traditional teacher-led methods. Table 2.4 not only highlights the inclusion of I-STEM characteristics but also if these activities align with best practices in student-centered pedagogy. The quality and depth of I-STEM integration across the thirty-four activities are further detailed through specific examples, providing a comprehensive understanding of how these characteristics are implemented within the thirty-four activities.

Table 2.4: Key Characteristics of Integrated STEM in STEM Activities

Activity	Real World Problem	Engineering	Context Integration	Content Integration	STEM Practices	21st-Century Skills	STEM Career Awareness	Student-Centered
1	Y	Y	Y	Y	N	N	Y	Y
2	Y	Y	Y	Y	Y	Y	Y	Y
3	Y	Y	Y	Y	Y	Y	Y	N
4	Y	Y	Y	Y	Y	Y	Y	Y
5	Y	Y	Y	Y	Y	Y	Y	Y
7	Y	Y	Y	Y	Y	Y	N	N
8	Y	Y	N	N	Y	Y	N	Y
9	Y	Y	Y	Y	Y	Y	Y	N
10	Y	Y	Y	Y	Y	Y	Y	Y

Activity	Real World Problem	Engineering	Context Integration	Content Integration	STEM Practices	21st-Century Skills	STEM Career Awareness	Student-Centered
11	Y	Y	Y	Y	Y	Y	Y	Y
12	Y	Y	Y	Y	Y	Y	Y	Y
13	Y	Y	Y	Y	Y	Y	Y	Y
14	Y	Y	Y	Y	Y	Y	Y	Y
15	Y	Y	Y	Y	Y	Y	Y	Y
16	Y	Y	Y	Y	Y	Y	Y	Y
17	Y	Y	Y	Y	Y	Y	Y	Y
18	Y	Y	Y	Y	Y	Y	Y	N
19	Y	Y	Y	Y	Y	Y	Y	Y
20	Y	Y	Y	Y	Y	Y	Y	Y
21	Y	Y	Y	Y	Y	Y	Y	Y
22	Y	Y	Y	Y	Y	Y	N	Y
23	Y	Y	Y	Y	Y	Y	Y	Y
24	Y	Y	Y	Y	Y	Y	N	Y

Activity	Real World Problem	Engineering	Context Integration	Content Integration	STEM Practices	21st-Century Skills	STEM Career Awareness	Student-Centered
25	Y	Y	Y	Y	Y	Y	Y	Y
26	Y	Y	Y	Y	Y	Y	Y	Y
27	Y	Y	N	N	Y	Y	Y	Y
28	Y	Y	Y	Y	Y	Y	Y	Y
29	Y	Y	Y	Y	Y	Y	Y	N
30	Y	Y	Y	Y	Y	Y	Y	Y
31	Y	Y	Y	Y	Y	Y	N	Y
32	Y	Y	Y	Y	Y	Y	Y	Y
33	Y	Y	N	N	Y	Y	Y	Y
34	Y	Y	Y	Y	Y	Y	N	Y

Qualitative Analysis of Key I-STEM Characteristics

This section provides a detailed exploration of each key characteristic observed in the STEM activities. The quantitative analysis presents results by sub-categories, showing the frequency of the core characteristics across the activities. Following this, the qualitative analysis delves deeper into how these characteristics are implemented, focusing not just on their presence but also on the quality and depth of their integration within the activities. The discussion is integrated with each theme to contextualize the findings and provide insights.

Real-World Problems

The real-world problems in each I-STEM activity were categorized as pure STEM or STEM relevant (Pleasants, 2020) and whether it was a community-based problem. The analysis revealed that twenty-four activities were incorporated as "pure STEM" problems and ten as both STEM-relevant and community-based (see Table 2.5).

Table 2.5: Frequency of Sub-Categories of Real-World Problems

Real-World Problem	Number of Activities
Pure STEM Activities	24
STEM Relevant	10
Community-Based Problems	10

Pure STEM activities were designed to immerse students in real-world problems, requiring them to apply scientific, engineering, and mathematical concepts to develop solutions. Engaging with engineering challenges, twenty-four pure STEM activities provided opportunities for students to apply science and math to design solutions (see Table 2.4). As highlighted by English (2017) and Stohlmann et al. (2012), these activities not only involve technical design but also promote a deeper understanding of scientific concepts and mathematical reasoning.

A quality example of a pure STEM problem is the activity "Catch Me if You Can," where students are tasked with designing a trap for a mischievous gingerbread man. This activity encapsulates the essence of pure STEM by requiring students to engage in the engineering design process while integrating scientific and mathematical reasoning. Students were tasked to create a trap that remains balanced until an external force—either a push or a pull—is applied, encouraging the exploration of fundamental physics principles such as forces and balance. Additionally, students apply mathematical concepts to calculate dimensions, angles, and necessary forces, ensuring that the trap functions as intended. The challenge thus extends beyond creating a viable design; it involves understanding the underlying scientific principles that dictate the trap's operation.

While these pure STEM tasks engage students in problem-solving, they fall short of integrating broader societal discussions around sustainability and environmental responsibility. As Pleasants (2020) points out, most real-world problems are not strictly engineering design issues, even though some may fall into that category. For example, "Wacky Weather," focuses on meteorology and the technical tools and methods used for weather forecasting; it does not explore the financial, physical, and emotional impact of extreme weather events on communities. This limited perspective could leave students without a comprehensive understanding of the real-world consequences. Similarly, the "Smashing Milk Cartons" activity involves applying STEM content to reduce the amount of garbage but overlooks the environmental implications of waste management. Although using the technical aspects of design as a lens for learning STEM concepts is valuable, educators must consider if this approach adequately prepares students for the complex, multifaceted problems they will encounter in the real world.

Our analysis identified ten activities that included STEM-relevant problems, all framed as community-centered. As Honey et al. (2014) emphasize, STEM learning becomes most powerful when students see its relevance to their lives and communities. For instance, the “Creating a Prosthetic Hand” activity was inspired by a specific need within the local school community: a student born without a hand struggled to press the Control + Alt + Delete keys on opposite sides of the keyboard simultaneously. Recognizing this challenge, the teacher introduced the problem to the class, building empathy and a sense of responsibility among the students to support their peers. The activity underscored the importance of respect, equal access, and inclusivity while highlighting the tangible impact of their work on someone within their own community.

To truly enhance student engagement, STEM curricula must transcend the traditional focus on delivering content and applications. Instead, it should foster a deeper understanding of how students' designs and solutions impact society, their communities, and the individuals within them. The "real-world problems" concept in STEM education demands critical reflection: *real for whom?* For many students, the term "real world" is abstract and disconnected from their lived experiences. To make these problems truly meaningful, they must resonate with students’ lives and communities. When students see their own realities reflected in the challenges they are asked to address, their motivation, engagement, and sense of purpose grow exponentially.

Grounding STEM learning in direct community connections is essential. These connections bridge the gap between theoretical knowledge and practical application, making learning relevant and impactful. By engaging with local stakeholders or addressing community-specific challenges—whether they are environmental, social, or technological—students develop a tangible sense of responsibility and citizenship. These interactions cultivate essential skills like empathy, collaboration, and critical thinking.

Moreover, the curriculum must prioritize issues that not only align with STEM but also extend beyond traditional, technocentric boundaries. This approach integrates interdisciplinary, societal, and ethical dimensions into STEM education. As emphasized by key policy documents (e.g., Caprile et al., 2015; Holdren et al., 2013; NRC, 2014), preparing students for complex, global challenges requires embedding these broader contexts into learning experiences. Unfortunately, many curricula fall short in achieving this aim.

When STEM learning is tied to community-connected, socially significant problems, it transforms into a dynamic and inclusive experience. Students learn to see themselves as active contributors to the well-being of their communities, equipped to tackle issues that matter most to the people and places they know. This direct connection ensures that "real-world" problems aren’t just a phrase but a lived reality for students, fostering a sense of relevance and empowering them to become informed, engaged, and effective agents of change in the world.

Centrality of Engineering

All 34 activities engaged students in EDC, offering students the chance to experience hands-on learning and problem-solving. However, these activities varied in the extent to which they engaged students in each phase of the design challenge, namely, learning about the problem and background, planning and implementation, and the testing and evaluating phase (see Table 2.6). This variation suggests differences in the depth of engagement with the EDC.

Table 2.6: Engineering

Engineering Design Challenge	**Number of Activities**
Problem and Background phase	34
Planning and Implementation phase	33
Testing and Evaluating phase	33

First, all thirty-four activities included an initial phase where students learned about the problem and its background. However, the depth and breadth of this phase differed across activities. Some activities briefly introduced the problem and offered minimal context. This approach could lead students with a limited understanding of the problem's complexity, potentially affecting their ability to engage in meaningful problem-solving later in the process (Pleasants et al., 2021). In contrast, other activities emphasized a thorough understanding of the problem, requiring students to grasp the issue in detail before moving on to consider potential solutions. By providing a comprehensive background, these activities fostered a more authentic context for the engineering challenge, helping them connect classroom learning to real-world applications (Bethke Wendell & Rogers, 2013). The importance of this phase is underscored by research, which indicates that students are more motivated and better equipped to develop innovative solutions when they have a solid grasp of the problem they are attempting to solve (Cunningham & Lachapelle, 2014).

The activity "Blasting Off With Engineering" engaged students in a hands-on learning experience by framing the challenge within a real-world context. Students received a memorandum from a fictional toy company, which introduced the task of designing a flying toy rocket. This memorandum provided essential background information and explained the company's expectations. The design challenge included specific constraints: the rocket had to be safe for school use, demonstrate predictable or easily adjustable behavior, and be built with cost-effective materials. These design constraints mirrored real-world considerations in product development, such as prioritizing safety, ensuring functionality, and managing budgets. The involvement of the fictitious toy company served as a client-like presence, clearly communicating the requirements for the rocket, guiding students through the planning phase, and setting the stage for what steps would follow. This approach aligns with research highlighting the importance of explicitly teaching students to identify and work within constraints, as this skill is fundamental to effective problem-solving (Kolodner et al., 2003).

In the planning and implementation phase, thirty-three activities engaged students, though the quality and depth of engagement varied. The high-quality activities provided resources such as articles, videos, and hands-on experiments to support the research and planning process. Those activities encouraged them to explore how similar problems had been addressed in various contexts, allowing them to gain insights that could inform their planning. This phase involved sketching designs, discussing potential solutions in small groups, and refining ideas through collaborative thinking. By incorporating a range of resources and encouraging collaborative brainstorming, these activities supported diverse idea generation and critical evaluation of potential solutions, reinforcing the iterative nature of the engineering design process (Cunningham & Hester, 2007).

Thirty-three activities engaged students in the testing and evaluating phase, assessing the efficacy of their prototypes. However, the quality of engagement in this phase varied across activities. Some activities provided students with a structured environment to test their designs systematically, allowing them to collect data and analyze whether their prototypes met the established criteria and constraints from the planning phase. These activities emphasized an iterative process, where students critically evaluated their design choices, identified materials best suited for the task, and refined their prototypes based on test results. For example, “Blasting off with Engineering,” engaged students in a comprehensive design challenge that combined engineering, physical science, and mathematics. This challenge allowed students to participate in the full engineering design process, where they collected and utilized data from a series of science inquiry activities to investigate various factors influencing the rocket’s flight. The activity culminated in a final rocket launch, where students tested their modified rockets to assess performance against the specified constraints. Students then reported back to the client, presenting their designs and explaining how their modifications met the criteria. This step not only reinforced the importance of the engineering design process but also highlighted the role of data-driven decision-making in developing effective solutions. This approach also reinforced the application of scientific concepts and engineering practices while mirroring the real-world engineering process, where iterative testing and modification are key to successful design (Mehalik et al., 2008).

However, other activities did not fully engage students in this iterative evaluation. For instance, some activities only allowed for a single round of testing without adequate opportunities for students to reflect on their findings or make improvements. This lack of depth in the testing and evaluating phase may limit students' understanding of the iterative nature of engineering design, as research indicates that hands-on experimentation and repeated modifications are crucial for enhancing students' problem-solving skills and deepening their conceptual understanding (Cunningham & Lachapelle, 2014).

Context Integration

The analysis of thirty-four activities revealed varying levels of alignment between the EDC and the content learning objectives. Among these, twenty-one activities directly aligned their content learning objectives with the EDC. Of these twenty-one activities, ten employed a fictitious client who communicated throughout the process to guide learning. However, three activities revealed no context integration, in those activities, the context was coming from the EDC, but it didn't include the opportunity for students to apply science and math content to the EDC (see Table 2.7).

Table 2.7: Context Integration

Context	Number of Activities
Activities directly aligned content learning objectives with ED using client involvement	10
Activities directly aligned content learning objectives with EDC without client involvement	21
No context integration	3

The activity, "Straw Rockets Are Out of This World," exemplifies how science and math integrated into an engaging engineering design challenge. Students actively participate in the engineering design process as they design, build, and test straw rockets.

Before diving into the hands-on component, they first explore fundamental principles of rocket functionality, focusing on Newton's third law of motion, which states that for every action, there is an equal and opposite reaction. This concept explains that when a rocket expels gas in one direction, it propels forward in the opposite direction.

During the challenge, students apply their understanding of force and motion to make informed design decisions. They select three different launch angles to test, adjusting the launcher accordingly. After launching the rockets, students measure the distance each rocket travels, analyze the data, and reflect on how the launch angles influenced performance. This iterative design process allows them to engage with scientific concepts both theoretically and practically, deepening their learning.

Effective STEM activities align content knowledge with hands-on applications, enabling students to understand the real-world relevance of their projects (Lachapelle & Cunningham, 2014). When STEM challenges are framed within meaningful contexts, students not only engage more deeply but also connect their learning to broader implications, such as how their designs might impact people or communities. This activity exemplifies context integration by bridging theoretical principles and practical design decisions, ensuring students experience how Newton's laws function in real-world scenarios (McComas & Burgin, 2020). Such interdisciplinary, hands-on learning fosters critical thinking, problem-solving, and a deeper understanding of STEM concepts.

Content Integration

Content integration within the thirty-four activities varied. The activities included different combinations of STEM disciplines: nine activities integrated science and engineering; fifteen incorporated science, engineering, and math; seven focused on engineering and math; and six activities combined English Language Arts (ELA) with STEM disciplines. Notably, three activities showed no integration of other content areas, focusing solely on engineering (see Table 2.8).

Table 2.8: Content Integration

Content	**Number of Activities**
Science + Engineering	9
Science + Engineering + Math	15
Engineering + Math	7
ELA + STEM	6
Engineering only	3

The integration of context and content within EDC is essential for fostering interdisciplinary learning. This overlap plays a critical role in engaging students, promoting cognitive understanding, and aligning STEM content with real-world applications (Berland & Steingut, 2016; Roehrig et al., 2021). However, the study identified instances where certain activities lacked this integration, focusing exclusively on engineering content while neglecting other STEM disciplines. For example, in the activity "A System of Systems," students explored structural engineering by learning how teams collaborate to define and solve problems through design, engineering, and construction. They used photos and speaker presentations to answer questions about the structure, function, and purpose of specific components, gaining an understanding of how different materials work together as systems to address challenges. However, this activity only emphasized engineering, with no integration of scientific concepts or mathematical reasoning.

Similarly, in the “Integrating Design” activity, students participated in a design challenge where they created a system to move water or marbles from one location to another using PVC pipes. While this activity promoted design thinking, it did not incorporate other STEM disciplines such as science or mathematics, limiting the depth and breadth of student learning. These activities, while valuable in introducing students to engineering concepts, missed the opportunity to highlight the interconnected nature of STEM. Without integrating scientific principles, mathematical reasoning, or interdisciplinary knowledge, students were not encouraged to use diverse concepts to inform and improve their design choices. As a result, the scope of learning remained narrow, failing to foster the holistic learning experience that is essential for meaningful STEM education. Incorporating multiple STEM disciplines within design challenges enriches learning and better prepares students to solve complex, real-world problems through interdisciplinary thinking.

When EDCs focus solely on engineering without meaningful integration of science or mathematics, students may develop a fragmented perception of STEM as a collection of isolated fields, rather than an interconnected system (Pleasants et al., 2019). Without explicit connections to scientific principles or mathematical models, students are more likely to rely on trial-and-error approaches during prototyping. While experimentation is an important part of the engineering design process, over-reliance on trial-and-error limits students’ ability to engage deeply with problem-solving and develop evidence-based reasoning (McComas & Burgin, 2020; Moore et al., 2014; Roehrig et al., 2021).

While the majority of the activities, which thirty-one, did incorporate multiple disciplines, the degree of integration and its meaningfulness varied, highlighting a critical aspect of effective I-STEM education. Effective I-STEM education requires the integration of two or more STEM disciplines, promoting a deeper understanding of how these fields intersect and apply to real-world problems (Brown & Bogiages, 2019; Kelley & Knowles, 2016). However, integration goes beyond merely including multiple disciplines; it requires students to understand the connections across the range of content within a lesson (Dare et al., 2018; Tran & Nathan, 2010). This study found that while thirty-one activities (see Table 2.7) included multiple disciplines, not all of them provided clear linkages or meaningful integration, which is essential for students to understand the interdisciplinary nature of STEM.

When STEM activities integrate multiple disciplines, students gain insight into how knowledge from various fields converges to solve complex problems. Effective EDCs ensure that students not only design and build prototypes but also apply scientific theories, mathematical reasoning, and technological tools to refine their solutions. This interdisciplinary approach promotes higher-order thinking and cognitive engagement, as students understand how STEM knowledge is applied within real-world contexts (Berland & Steingut, 2016).

Therefore, context and content integration are not independent processes but mutually reinforcing components of effective EDCs. Activities that balance both components help students experience STEM as an interdisciplinary framework, equipping them with the knowledge and skills necessary to tackle real-world challenges. This comprehensive approach enhances student engagement and promotes deeper learning, preparing students to succeed in STEM fields where integration across disciplines is essential (Pleasants and Olson 2019).

The activity “Designing a Hovercraft” serves as a strong example of content integration, effectively blending science, engineering, mathematics, and English Language Arts (ELA) to create a rich, multidisciplinary learning experience. The integration of science within EDC allows students to engage deeply with scientific principles in meaningful, hands-on contexts and bridges theoretical knowledge and practical application, helping students explore key concepts while solving real-world problems (Berland & Steingut, 2016; Moore et al., 2020). EDC encourages students to apply scientific inquiry methods—such as observation, experimentation, and analysis—while iteratively designing, testing, and refining their solutions.

For example, in “Designing a Hovercraft,” activity students explored the science of push and pull forces, friction, gravity, and air resistance while designing and testing their hovercrafts. By adjusting variables such as air pressure and surface contact, students engaged with core physical science principles to optimize their hovercraft’s performance. This type of content integration promotes deeper conceptual understanding, as students must apply scientific knowledge to solve design challenges. Rather than merely learning these concepts in isolation, students see how forces and interactions directly affect their engineering solutions, reinforcing the real-world relevance of science (Pleasants et al., 2019).

In Twenty-one activities, mathematics was integrated primarily for data collection and analysis. For example, in the activity “Designing a Hovercraft,” students measured flight distance, applying quantitative reasoning skills in a meaningful, hands-on context.

While this integration of mathematics within EDC provides students with valuable opportunities to connect mathematical concepts to real-world problems, it also reveals limitations in how math is typically utilized in STEM education.

Research suggests that mathematics in science classrooms is often underutilized, restricted to procedural tasks such as measurement or data analysis, rather than being applied as a tool for deeper problem-solving and conceptual understanding (English, 2016; Moore et al., 2014). Though these activities highlight the relevance of mathematical concepts like measurement, scaling, and optimization, the scope is often narrow, limiting the potential for students to engage fully with interdisciplinary learning.

When math is used solely for data-related tasks, students miss opportunities to explore how mathematical reasoning can inform design decisions and support the iterative process of building and refining engineering solutions. To foster meaningful learning, EDCs must move beyond basic mathematical applications and integrate more complex concepts that encourage optimization, prediction, and critical decision-making (Roehrig et al., 2021). Expanding the role of mathematics in STEM activities can strengthen students' ability to apply mathematical principles across disciplines, preparing them for real-world problem-solving with a more comprehensive, interdisciplinary approach.

The inclusion of ELA in the "Designing a Hovercraft" activity added another layer of content integration. Using the fictional character Captain Arsenio, inspired by real-life pilot Bernasconi, created an engaging narrative that enhanced the lesson. Storytelling in STEM education has been shown to increase student motivation and engagement by providing a narrative context for learning (Billington et al., 2013). The narrative approach also allowed students to improve their literacy skills, such as reading comprehension and narrative analysis, while deepening their understanding of engineering design concepts.

Overall, this activity demonstrates how content integration enriches the learning experience by allowing students to apply their knowledge across multiple disciplines. This approach aligns with research that emphasizes the value of interdisciplinary STEM education, where students can engage in complex, authentic problem-solving tasks that mirror the work of professionals in the field (Lachapelle & Cunningham, 2014). Such integration helps students make meaningful connections between subjects and better understand the practical applications of their learning (Moore et al., 2020).

STEM Practices

The analysis of thirty-four STEM activities revealed varying levels of student engagement with essential STEM practices. These practices include asking questions, defining problems, planning and carrying out investigations, analyzing and interpreting data, engaging in mathematical and computational thinking, constructing explanations, designing solutions, and engaging in evidence-based reasoning (NRC, 2012). Across the activities, thirty-three provided students with opportunities to engage in the questioning and problem-defining phase, while thirty-two allowed students to plan and carry out investigations. Additionally, thirty-three activities engaged students in data analysis, computational thinking, and evidence-based reasoning, while thirty-one activities allowed students to practice obtaining, evaluating, and communicating information (see Table 2.9). However, the quality and depth of these opportunities varied across the activities.

Table 2.9: STEM Practices

STEM Practices	Number of Activities
Asking questions & defining problems	33
Planning and carrying out investigation	32
Developing and using models	32
Analyzing and data interpretation	33
Using mathematical and computational thinking	33
Constructing explanations and designing solutions	33
Engaging in arguments from evidence	33
Obtaining, evaluating, & communicating	31

The engineering practices outlined in the NGSS are intentionally aligned with the EDP. This alignment encourages students to engage in iterative problem-solving, construct prototypes, and make evidence-based decisions by gathering, analyzing, and testing data (Berland & Steingut, 2016). Through this process, students experience firsthand how engineering integrates with scientific inquiry and mathematical reasoning, reinforcing the interdisciplinary nature of STEM education. It is, therefore, unsurprising that thirty-one activities from the curriculum incorporated mathematics, science, and engineering practices. These activities reflect the curriculum's emphasis on EDCs as a core instructional strategy, providing opportunities for students to apply STEM disciplines. As shown in Table 2.7, the majority of the curriculum integrates these practices, providing students with opportunities to develop essential skills such as data analysis, experimentation, optimization, and design thinking.

STEM practices play a crucial role in promoting student agency, defined as the ability of students to take ownership of their learning by making decisions, exploring multiple solution pathways, and reflecting on their processes (Kelley & Knowles, 2016; Roehrig et al., 2021). In this study, the degree of student autonomy varied across activities. Out of 34 activities analyzed, 29 activities encouraged student-centered learning by allowing students to take charge of the design process from brainstorming to building and redesigning (see Table 2.10). In contrast, five activities were more teacher-centered, limiting student involvement in decision-making. In I-STEM education, promoting student agency requires that activities foster epistemic agency—where students actively shape their learning experience rather than passively receiving knowledge (Koehler et al., 2015). When students are empowered to make decisions, explore solutions, and take risks, they form deeper connections between theoretical concepts and practical applications, making the learning process more meaningful and relevant.

Table 2.10: Student-Centeredness

Centeredness	Number of Activities
Student-Centered	29
Teacher-Centered	5

A key finding from this study is that twenty-one activities with explicit connections to data collection and analysis provided students with more meaningful opportunities to develop evidence-based reasoning skills. For example, in the activity "A House for Chase the Dog," students tested the water resistance and durability of various materials. They used the data from these experiments to refine their designs, reinforcing their understanding of material properties while applying evidence-based reasoning to improve their solutions. This iterative process mirrors real-world engineering practices, where problem-solving relies on continuous iteration and data-driven decision-making (Cunningham & Lachapelle, 2014).

Evidence-based reasoning is a cornerstone of STEM education, requiring students to collect, analyze, and interpret data to support their design decisions (Berland & Steingut, 2016). However, the success of these practices depends not only on the curriculum itself but also on how it is implemented in the classroom. While written curricula promote student agency through STEM practices, effective teacher facilitation is essential to create meaningful learning experiences.

Teachers play a crucial role in fostering student autonomy by providing flexible opportunities for exploration, encouraging students to take risks, and supporting them through inquiry and problem-solving. In this setting, the teacher's role shifts from director to facilitator, guiding students without prescribing specific solutions (Moore et al., 2020). Skilled facilitation involves asking thought-provoking questions, helping students organize and analyze data, and encouraging them to engage deeply with evidence-based reasoning. By adopting these strategies, teachers empower students to take ownership of their learning, fostering a deeper engagement with STEM practices and enhancing their capacity for data-driven decision-making and problem-solving.

Twenty-First Century Skills

This study highlights the integration of twenty-first-century skills—creativity, communication, collaboration, and critical thinking—across thirty-four I-STEM activities, facilitated primarily through design challenges. These challenges provided students with opportunities to explore multiple solutions, a critical component of fostering creativity and effective problem-solving (Kloser et al., 2018; Moore et al., 2020). The engineering design challenge (EDC) promotes these skills by embracing an open-ended approach where students actively engage in building and refining their ideas, emphasizing that there is no single correct solution (Stretch & Roehrig, 2021; Petroski, 2016; Simpson et al., 2018).

The findings suggest that the iterative nature of the EDC plays a pivotal role in nurturing both creativity and critical thinking. By allowing students to test and refine their ideas, the EDC fosters innovation and encourages students to experiment with various solutions. This iterative process supports deeper cognitive engagement by challenging students to continuously improve their designs through feedback and evidence-based adjustments. However, the effectiveness of these activities heavily relies on the quality of instruction. Educators must encourage students to explore multiple design solutions actively, as students may otherwise limit themselves to a single solution, restricting the potential for creative thinking and meaningful problem-solving.

The study also underscores the importance of collaboration as a fundamental element embedded across the thirty-four activities. Students were expected to work in groups to brainstorm ideas, co-construct solutions, and design prototypes collaboratively. While these activities were designed to promote teamwork, the actual quality of collaboration is dependent on how effectively teachers facilitate group work. Curriculum evaluation alone cannot fully assess the dynamics of collaboration in the classroom. Research emphasizes that successful collaboration requires intentional facilitation by educators to ensure all students participate meaningfully, provide constructive feedback, and engage in critical discussions that foster deeper understanding and creativity (Wagner, 2010).

Moreover, the findings reveal that teachers play a crucial role in ensuring that activities promote meaningful engagement with twenty-first-century skills. Without effective teacher guidance, even well-designed activities may not fully develop students' creativity, critical thinking, or collaboration skills. Facilitating an inclusive environment where all students feel empowered to contribute is essential for realizing the full potential of I-STEM activities. Teachers must also create spaces for open communication and reflective thinking, ensuring that students are not only solving problems but also learning from the process and improving their approaches.

STEM Career Awareness

To foster future participation in STEM careers, integrating career awareness into STEM education is essential. The analysis of the activities revealed that STEM career awareness was integrated into twenty-eight activities. Most of these (twenty-eight) addressed STEM careers by simply mentioning the roles of scientists, engineers, and other professionals (see Table 2.11.) These activities also introduce students to a broader range of STEM careers, such as geoscientists, civil engineers, structural and technical engineers, and marine biologists.

Table 2.11: STEM Career Awareness

STEM Careers	**Number of Activities**
Mention of STEM careers	28

Mention of Female STEM Professional	7
No mention of STEM careers	6

Additionally, seven activities featured female role models in STEM through story characters, serving to inspire and motivate students while challenging traditional gender roles in these fields. A notable example is the “Flying Machines” activity, which centers on Violet, a girl passionate about inventing machines. Unlike her peers who play with dolls and tea sets, Violet prefers tinkering with tools. Despite being teased for her unconventional interests, her mechanical skills ultimately make her the hero of the story, showcasing the power and value of unique talents. By incorporating Violet’s story into the activity, students were encouraged to adopt a similar mindset as they tested their flying machines, thinking like inventors and approaching design challenges with curiosity, creativity, and resilience. This narrative not only fostered perseverance and creativity but also provided a relatable role model for girls, showing them that they, too, can thrive in traditionally male-dominated STEM fields. The connection between the story and the hands-on activity helped students see the relevance of STEM skills in real-world contexts and underscored the importance of diverse talents in solving problems.

A significant challenge, however, is that even students who excel in STEM subjects often do not see themselves pursuing STEM careers, particularly those from historically underrepresented groups, such as women and minorities (Capobianco et al., 2011; Rodriguez et al., 2017). I-STEM education plays a vital role in addressing this gap by not only introducing students to various career pathways but also by emphasizing the diversity within STEM fields to positively shape students’ perceptions (Tai et al., 2006).

Connecting STEM learning to students' personal experiences and cultural backgrounds is particularly important for fostering strong STEM identities, especially among diverse student populations (Ryu et al., 2018; Carlone et al., 2014; Sias et al., 2017). When students see how STEM concepts relate to their own lives and communities, they are more likely to develop a sense of belonging in these fields. This connection can transform their perception of STEM from an abstract academic pursuit into a tangible vision of themselves as future contributors to these careers.

Incorporating diverse STEM careers into the curriculum is essential for helping students envision their potential futures in these fields. By highlighting various roles and including relatable role models, particularly those from underrepresented groups, STEM education can help students see the relevance of these fields to their lives and foster a more inclusive vision of what a STEM professional looks like. This approach not only increases awareness but also nurtures interest and identity in STEM, paving the way for a more diverse and engaged future workforce.

Conclusions

This study conducted a systematic analysis of thirty-four STEM activities published by the NSTA to evaluate their alignment with the core characteristics of I-STEM education. The results revealed that these activities embodied several essential I-STEM features, including the use of real-world contexts, incorporation of EDC, integration of multiple STEM disciplines, development of twenty-first-century skills, emphasis on STEM practices, learner-centered approaches, and promotion of STEM career awareness. The integrated STEM rubric developed in this study offers a valuable tool for assessing and enhancing the alignment of STEM activities with I-STEM best practices. It provides educators and curriculum developers with a clear framework for evaluating existing curricula and guiding the creation of new, high-quality STEM learning experiences.

However, the quality and depth of integration varied, with some activities demonstrating stronger alignment than others. The findings from this study emphasize the importance of aligning STEM curricula with I-STEM characteristics to prepare students to become critical thinkers, problem-solvers, and innovators. An EDC plays a pivotal role in bridging STEM content and practices, ensuring that students engage with integrated learning experiences that reflect the complex, interdisciplinary nature of real-world challenges.

A key finding from this study is the critical role of EDC in fostering overlaps between I-STEM characteristics. The presence of EDC in all analyzed activities served as the connective tissue between context and content, STEM practices, and interdisciplinary learning. The inclusion of an EDC inherently promotes the integration of scientific and mathematical concepts within engineering challenges, encouraging students to engage in problem-solving processes that mirror real-world applications. This overlap enhances the effectiveness of STEM education by providing students with opportunities to apply theoretical knowledge in practical scenarios, strengthening their conceptual understanding while promoting cognitive engagement.

The broader implications of these findings, along with recommendations for future research and practice, are discussed in subsequent sections to further support the advancement of integrated STEM education. By continuously refining curriculum design and leveraging tools such as the integrated STEM rubric, educators and curriculum developers can enhance the effectiveness of STEM education, ensuring that students are equipped with the skills and knowledge necessary to thrive in future STEM careers.

Implications

The integrated STEM rubric developed in this study holds significant potential as a versatile tool for assessing and enhancing integrated STEM education. This evaluation can be critical for educators as they design or refine their lesson plans, helping them to ensure that their instructional strategies are aligned with best practices in integrated STEM education. In professional learning settings, the rubric serves as a guide for teachers as they develop and improve their STEM lesson plans. By using the rubric, teachers can gain a clearer understanding of the essential components of high-quality integrated STEM education. It helps them to design lessons that incorporate interdisciplinary connections, hands-on problem-solving, and opportunities for students to apply scientific, technological, engineering, and mathematical concepts in meaningful ways. Moreover, it can assist teachers in aligning their instructional practices with key educational goals, such as fostering critical thinking, promoting collaboration, and encouraging creativity.

Future Work

Building on the findings of this study, future research should investigate how the core characteristics of integrated STEM (I-STEM), as identified in this analysis, directly influence student outcomes. This includes examining the impact of these practices on students' learning, engagement, problem-solving abilities, and long-term interest in pursuing STEM careers. Understanding how specific elements—such as real-world contexts, interdisciplinary content integration, and EDC—affect student performance would provide deeper insights into which strategies are most effective in promoting meaningful STEM learning. Such research could also explore how these practices support the development of critical twenty-first-century skills, including creativity, collaboration, and critical thinking, helping educators refine their approaches to ensure lasting educational impact.

Another promising avenue for future work involves expanding the integrated STEM rubric developed in this study. Applying the rubric to a broader range of STEM activities across different grade levels and educational settings would provide a more comprehensive understanding of how I-STEM principles are implemented in diverse contexts. This expanded analysis could reveal patterns of success and highlight areas for improvement in curriculum design and instructional strategies. Moreover, the rubric could be adapted to assess the effectiveness of extracurricular programs, such as STEM clubs, summer camps, and community-based initiatives, offering insights into how informal learning environments contribute to STEM education.

Future research could also investigate the ways teachers interpret and adapt I-STEM curricula to meet the needs of their students. Given the variation in implementation observed in this study, further exploration into how teachers balance curriculum goals with the realities of their classroom contexts would provide valuable guidance for professional development programs. Studies could explore how educators navigate challenges such as time constraints, limited resources, and varying levels of student readiness while implementing interdisciplinary STEM lessons. Identifying effective strategies for overcoming these barriers would support teachers in delivering high-quality STEM instruction that aligns with I-STEM principles.

In addition, longitudinal studies examining the sustained impact of I-STEM education on students’ academic trajectories and career choices would offer critical insights into the long-term benefits of integrated STEM approaches. Tracking students over time could reveal how exposure to interdisciplinary STEM learning influences their career aspirations, college readiness, and persistence in STEM fields. Such research would also help policymakers and educators better understand the role of STEM education in addressing equity issues by examining how these practices impact students from diverse backgrounds, including those traditionally underrepresented in STEM fields.

Lastly, future research should explore how I-STEM practices can be further aligned with equity-focused initiatives. Investigating how inclusive pedagogies and culturally responsive teaching strategies can be integrated into I-STEM frameworks would ensure that STEM education becomes more accessible and engaging for all students. This work could focus on developing activities that connect STEM learning to students’ lived experiences, community challenges, and social issues, fostering a sense of relevance and empowerment. By aligning I-STEM practices with equity goals, educators can inspire a broader range of students to pursue STEM pathways, ultimately contributing to a more diverse and inclusive STEM workforce.

Limitations

One limitation of this study is its focus exclusively on STEM activities published by the NSTA. While NSTA resources are widely respected and used in K–12 education, the narrow scope of this study means that the findings are based on a specific subset of available STEM curricula. This focus limits the generalizability of the results, as it may not fully capture the diversity of integrated STEM resources used in various educational settings. STEM education encompasses a broad spectrum of approaches, from locally developed curricula to those created by other national and international organizations, each potentially offering unique perspectives and instructional strategies.

By relying solely on NSTA-published activities, the study may overlook valuable insights from other sources that also emphasize interdisciplinary STEM learning, problem-based challenges, and twenty-first-century skill development. Curricula from other organizations, districts, and countries might offer different approaches to implementing student-centered learning, real-world problem-solving, and engineering design challenges, providing a richer understanding of how integrated STEM education can be effectively delivered in diverse contexts.

Chapter 3: Manifestation of Integration into Practice:

A Single Case Study of an Elementary Science Teacher in Action

The inclusion of engineering in K–12 science education is growing increasingly common in the United States through *A Framework for K–12 Science Education* (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013). The framework articulates the role of engineering as a vehicle for students to learn scientific concepts and to engage them in meaningful learning (National Research Council, 2012). With the adoption of recent science standards (i.e., NGSS); teachers are faced with the task of integrating engineering design into their science instructions and making connections between Science, Technology, Engineering, and Mathematics (STEM) disciplines in their instructions. This is partly daunting for elementary teachers, given their minimal preparation in engineering (Banilower et al., 2013).

While STEM education is recognized by educators and research communities as important, there is no common understanding or agreement on the nature of STEM education as an integrated endeavor. Consequently, K–12 teachers have limited guidelines and teaching models to follow regarding how to teach integrated STEM (NGSS Lead States, 2013). Without clear guidelines, the implementation of integrated STEM education comprises a broad range of approaches (Moore et al., 2020). Because of this, it is essential to understand the ways teachers use integrated STEM approaches in their instructions. Such teaching experiences will provide valuable perspectives on how STEM integration is represented in practice. Thus, the goal of this study is to examine how an elementary school teacher enacted STEM integration in her science classroom.

Specifically, this study aims to answer the following research questions: a) In what ways does an elementary teacher make connections between different STEM disciplines? b) How did contextual integration manifest in her integrated STEM implementation? c) How did content integration manifest in her integrated STEM implementation?

Conceptual Framework

Integrated STEM education can be modeled and defined in a number of ways; some features are common and exist across different models. This work is driven by Roehrig and colleagues' framework (Roehrig et al., 2021). This framework includes seven key characteristics of integrated STEM: focus on real-world problems, centrality of engineering, context integration, content integration, STEM practices, twenty-first-century skills development, and STEM careers awareness. This framework views integrated STEM as contextualizing learning in real-world problems, using engineering design challenges to contextualize student learning of science, and providing students with a realistic representation of how STEM knowledge is used beyond K–12 education.

Engineering is considered a central element of integrated STEM (Moore et al., 2014). The teacher frames the activity from a real-world problem perspective, which helps situate students' learning in STEM in an authentic context to make learning relevant to students. As students engage in an engineering design challenge to develop solutions to an overarching real-world problem, they draw upon knowledge, skills, and content from multiple disciplines (e.g., Thibaut et al., 2018; Walker et al., 2018). Research shows that using real-world or authentic problems as a context for learning in integrated STEM spaces motivates students to learn STEM content (Kelley & Knowles, 2016). Furthermore, engaging students in learning through authentic engineering design problems improves student interest in science and engineering (Lachapelle & Cunningham, 2014; McClure et al., 2021).

Literature Review

The problems we face in this society are complex in nature and require the integration of multiple disciplines, concepts, and skills to solve. Therefore, educational reforms advocate for a change in how these disciplines are taught in schools, with an emphasis on the integration of STEM disciplines to teach students problem-solving skills and to model real-world problems (NRC, 2012; NAE & NRC, 2014). Researchers agree that integrated STEM instruction should use real-world contexts to engage students in authentic and meaningful learning (Kelley & Knowles, 2016; Sanders, 2019) that reflects the interconnectedness of the four STEM disciplines.

Despite the pedagogical drive for more integrated STEM in K–12 grade levels, research on STEM integration shows that there is no single definition or conceptualization of what STEM integration should look like (Moore et al., 2020; NAE & NRC, 2014). Various broad definitions of integrated STEM education exist in the literature and policy documents. For example, Moore, and colleagues (Moore et al., 2014) broadly defined integrated STEM education as “an effort to combine some or all of 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” (p. 38). Similarly, Kelley and Knowles (2016) defined integrated STEM education as “the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning” (p. 3).

Since there is no universal definition of integrated STEM out there, it makes implementation even more challenging; however, there is an emerging sense of agreement around several features that are indicative of quality integrated STEM instruction (see Table 3.1).

Table 3.1: Key Features of Integrated STEM and Supporting Research

Feature of Integrated STEM	Supporting Research
Learning situated within a real-world context	Breiner et al., 2021; Brown et al., 2011; Kelly & Knowles, 2016; Kennedy & Odell, 2014; Moore et al., 2014; Rinke et al., 2016; Sanders, 2009
Student-centered pedagogies	Breiner et al., 2021; Kelly & Knowles, 2016; Kennedy & Odell, 2014; Labov et al., 2010; Moore et al., 2014; Rinke et al., 2016; Sanders, 2009
21st century skills: Teamwork, communication, and critical thinking	Brown et al., 2011 Kennedy & Odell, 2014 Moore et al., 2014
Connections between STEM Disciplines	Brown et al., 2011 English, 2016 Herschbach, 2016 Kelly & Knowles, 2016 Kennedy & Odell, 2014 Labov et al., 2010

The inclusion of engineering into K–12 science classrooms is the way to integrate multiple STEM disciplines, given the interdisciplinary nature of the problems we currently face in this world, and the need to engage students in authentic learning to solve real-world problems. STEM policy documents (National Research Council, 2011, 2012; NGSS Lead States, 2013) highlight the importance of engineering. Some scholars (e.g., Bryan et al., 2015; Moore et al., 2014) suggested that infusing engineering context or problems in an integrated STEM curriculum can be central for integration. Additionally, Kelley and Knowles (2016) emphasize that engineering design can "provide the ideal STEM content integrator" (p. 5). Engineering can be viewed as a critical link to developing integrative STEM curricula and linked to several efforts to teach STEM subjects in an integrated manner (NAE & NRC, 2014).

The primary rationale for including engineering in science instruction is to enhance students' science learning (Apedoe et al., 2008; NAE & NRC, 2014). Furthermore, science learning can be enhanced by giving students an opportunity to apply science knowledge and also provide an authentic context for learning through an engineering design approach (Kelley & Knowles, 2016). From this perspective, engineering is introduced as an "iterative process that starts with identifying the problem and takes into account the identified constraints and meets the criteria for desired outcomes and ends with the solution" (p.6-7) (National Research Council, 2010). Typically, engineering-focused curricula incorporate design challenges to situate student learning. An engineering design challenge (EDC) involves a fictitious client with defined criteria and constraints to engage students in problem-solving. Students work in teams to build a prototype, test, evaluate, and communicate the solutions to the client. This process allows students to use scientific knowledge, employ computational thinking skills, and collaborate with others to co-construct knowledge related to design solutions.

Within K–12 classrooms in the United States, engineering is most commonly integrated into science classrooms through the *NGSS*, with the most common approaches to integrated STEM generally taking two forms: content and context integration (Moore et al., 2014). In content integration, a single unit or lesson includes learning objectives from multiple STEM disciplines. Research highlights that content integration can be achieved through multidisciplinary, interdisciplinary, or transdisciplinary approaches (Bybee, 2013), is argued by researchers that one approach is not superior to another (Rennie et al., 2012). On another hand, context integration involves contextualizing learning objectives from one discipline to connect other disciplines to provide a context that creates meaning, provides relevance, and serves as a motivator for students to learn the primary content (Moore et al., 2014). By contextualizing learning through real-world engineering problems, these integrative STEM approaches have been shown to help students better learn and apply science knowledge (Brophy et al., 2012; Moore et al., 2014).

The crosscutting concepts and core ideas presented in the framework of K–12 science education stress the importance of argumentation; one of the essential practices is to engage students in arguments from evidence. The *argument* practice is described differently in science and engineering contexts. For example, in science, the argument is used to make and support claims about natural phenomena; in engineering, it is used to develop the best possible solutions to engineering problems (National Research Council, 2012). Reaching conclusions in science is independent of context, but in engineering, the conclusions are based on the needs and demands of a particular client. In the real world, scientists and engineers engage in the argument practice by using evidence, but the underlying reasons are different (National Academy of Engineering, 2009). Engineering allows the use of science and mathematics, but it requires consideration of design criteria (e.g., performance, safety) and constraints (e.g., budget, client's needs, materials) (National Research Council, 2012).

Additionally, many scholars (e.g., Cunningham & Lachapelle, 2014; English, 2015; Moore et al., 2014; Stohlmann et al., 2012), agree that engineering experiences can develop students' understanding of the various roles of engineering in shaping the world around them, and how mathematics and science knowledge can be contextualized through engineering to enhance students' motivation and achievement. Teachers play a critical role in contextualizing students' learning and making connections among the STEM disciplines visible to students. Since research on the nature of STEM integration is limited, we seek to expand upon this literature base to better understand how elementary teachers incorporate and implement engineering design in their science classrooms to integrate content and context.

Methods

Research Design

A single case study design was employed in this study to examine how an elementary teacher used engineering design-based activities to engage and teach science content in an integrated STEM unit to students. According to Yin (2014), a single case study is best used if the goal is to examine a complex phenomenon, with the focus of the study on a single person, thing, or group. The boundary of this single case study is one integrated STEM unit taught by Ms. Ashley. This qualitative research design was selected because it allowed for an in-depth exploration of an integrated STEM unit implementation (Yin, 2017).

Context

The data in this study came from classroom observations of Ms. Ashley's elementary science classroom where she implemented an integrated STEM unit. Classroom videos were collected during the third year of a 5-year NSF-funded research project; teachers were videotaped during the implementation of their STEM units with each video corresponding to one class period (approximately 45 minutes).

Participant Context

Ms. A, a white female teacher in this study, had less than five years of teaching experience. She worked at an urban Midwestern elementary school with a diverse student population. More than 90% of the students at this school were students of color. Furthermore, more than half of the students at this school were English language learners and over 70% had access to free and reduced lunch.

Curriculum Context

Ms. A implemented an integrated STEM unit called *Claw Game*, which she co-developed with a team of teachers and educational researchers as part of a large NSF-funded project. Within the unit, students designed and tested an electromagnetic claw for an arcade game, given a set of criteria and constraints provided by the client. Students learned and applied scientific concepts surrounding magnetism and electromagnetism to their design solutions. Client letters and memos were provided to students throughout the unit. This unit comprised seven distinct lessons (see Table 3.2), each of which was intended to take at least one 50-minute class period. In this study, the unit was implemented for 15 class periods, but only 14 days were observed and recorded.

Table 3.2: Lesson Summary of The Claw Game

Lesson	**Lesson Focus**	**Lesson Summary**	**Connections to the NGSS Unit Standard**
1	Engineering	**Problem-Scoping:** At the beginning of the lesson, students are introduced to the client and the engineering design challenge (EDC) via a client letter. They review the engineering design process engage in problem-scoping and learn the criteria and constraints from the client letter.	3-5-ETS1-1
2	Science	**Science Investigation:** In this lesson, students learn background information on magnets and magnetic materials. Students investigate different aspects of electromagnets that affect the strength of the electromagnet. They identify and select a variable to test in the following lesson.	5-PS1-3
3	Science	**Science Investigation:** In this lesson, students investigate different aspects of electromagnets that impact the way magnets work. Students work in their small groups to carry out an experiment, testing how the number of coils affects electromagnet strength. They graph their data and write claims supported by evidence about the effect of coils on electromagnets.	3-5-ETS1-1, 3-5-ETS1-3, MS-PS2-3, MS-ETS1-1, MS-ETS1-2

Lesson	Lesson Focus	Lesson Summary	Connections to the NGSS Unit Standard
4	Science	**Science Investigation:** In this lesson, students carry out experiments to test variables that affect the strength of an electromagnet. They identify patterns in their data and create a poster to share their experimental results with the class.	3-5-ETS1-2, 3-5-ETS1-3, MS-PS2-3, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4
5	Engineering	**Plan and Design:** In this lesson, each team of students chooses another variable to test. They then collect data and create visual displays to look for patterns in their data. Using the information they have learned about electromagnets, students design and build a prototype electromagnet for the client. They then test their design to see how many washers it can pick up, learn about other groups' designs, and reflect on ways to improve.	5-PS1-3, 3-5-ETS1-3, MS-ETS1-3, MS-ETS1-4
6	Science	**Science Investigation:** In this lesson, students are introduced to a new client's need for a "tag" material to be placed on the toys in the game. They investigate which materials are magnetic and make a recommendation to the client about the "tag" material.	3-5-ETS1-3, MS-ETS1-1, MS-ETS1-3, MS-ETS1-4

Lesson	Lesson Focus	Lesson Summary	Connections to the NGSS Unit Standard
7	Engineering	**Redesign and Communication with the Client**: In this lesson, students redesign and retest their new designs based on a new set of criteria and constraints introduced by the client in the previous lesson. They then make a presentation to share their best design with the client, describing the results of their tests and the reasoning behind their design choices.	3-5-ETS1-2, 3-5-ETS1-3, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3 , MS-ETS1-4

NGSS Unit Standards	Description
5-PS1-3	Making observations and measurements to identify materials based on their properties.
3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-PS2-3	Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

NGSS Unit Standards	Description
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS-ETS1-3	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
MS-ETS1-4	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Data Collection

During the school year, the participant implemented her integrated STEM curriculum in her own classrooms. For each day of the unit's implementation, the teacher was observed by the researcher who took detailed field notes and collected videotaped recordings (implementation videos) of both whole-class and small-group instruction; memos were created by the researchers as a result of watching these recordings. The detailed field notes were carefully noted down by the researcher on what happened in each lesson including what was said by the teacher or how this teacher made connections between science and engineering explicit to students as a part of the note-taking process.

Fourteen days of the integrated STEM unit implementation were observed and recorded. Data sources included video and transcripts available for analysis. This dataset included approximately an equal representation of science-focused and engineering-focused activities (100 minutes of science and 107 minutes of engineering). Additional data sources included daily field notes taken by the researcher during the unit implementation and memos written by researchers while watching implementation videos.

Data Analysis

Data sources were analyzed in multiple phases. During the first phase of the analysis, a group of researchers first reviewed the field notes and video-recorded instruction several times, specifically looking at how science and engineering content were represented and integrated, noting instances where the teacher made connections between the disciplines in her instruction. The researchers observed each unit as a whole by identifying and labeling its major parts (e.g., identifying the problem, engaging in scientific investigation, planning, and designing). This process aided the researchers in identifying the sequence of the science and engineering lessons. The episodes of interest were then identified and transcribed, paying careful attention to the teacher's instruction. For the second phase of the analysis, the researchers selected and discussed one transcript as a group to build a codebook. Once the codebook was constructed, all the researchers then independently coded it. The last step involved coming into a consensus as a group after individual coding sessions.

Using deductive analysis based on the integrated STEM framework by Roehrig and colleagues, codes were consistently applied to the data (Berg, 2001). The researchers independently coded each lesson chunk by chunk to establish inter-rater reliability. When the four codes were applied to fourteen days of implementation, the research team consistently addressed discrepancies and reached an agreement on the codes (see Table 3.3).

Table 3.3: Codes

Codes	Description	
Context Integration [CXI]	When teachers situate students' learning in real-world scenarios through engineering design challenge	
Content Integration [CNI]	When a teacher connects content from two or more STEM disciplines (S, E, and/or M)	
	Explicit [Ex]	When the teacher makes a direct connection between two or more STEM disciplines
	Implicit [Im]	When the connections between two or more STEM disciplines have to be inferred.

Findings

Our findings revealed that Ms. Ashley integrated STEM disciplines in her lessons in two different ways: context integration and content integration.

Context Integration

Context integration happened throughout the integrated STEM unit, with the client letters being used by the teacher as an integrator. In order to situate student learning, Ms. Ashley utilized the client letters in three ways: to introduce the problems at the beginning of the lesson, to remind students of the client's needs throughout the unit, and as an avenue for students to communicate their ideas and learning to the client.

Client Letter Was Used to Contextualize Learning During Problem-Scoping Phase

The client's letter guided her instructions and provided context for students to learn during the problem-scoping phase. During this phase, students were introduced to the engineering design challenge (EDC). They engaged in problem-scoping by discussing and identifying specifics about the design challenge, described by the client in the first letter:

> Our company Arcade Inc. has a problem. We design and build arcade games. For some reason, people are losing interest in the game and not playing it as much. We need a new "claw" in hopes that customers will play more. We would like to give you a contract to develop an electromagnetic arm to replace a claw in the game.

This problem-scoping phase took place on Day 1 where she introduced her students to the fictitious client company "*Arcade Inc.*", who tasked students with addressing the design challenge. This introduction was done through a letter from the client and included as part of the teacher's instruction to situate students' learning in an authentic design context. The client letter contained background context and information relevant to the design challenge, including the design criteria and constraints.

Similarly, on Day 2 she stated that they would get further instruction from the company to start the electromagnet investigation. Specifically, she mentioned "in order to figure out how electromagnet works, we're gonna find out what we need to do. This is a memo from Arcade Inc." Furthermore, on Day 3, Ms. Ashley shared the client memo and the instructions the class received from the company, asking this class to come up with a list of things they could change about the electromagnet. She informed the students that they would be:

> creating a new attachment electromagnet arm for the claw game … [and] investigate electromagnet to find out how you [students] can make one [by] doing some experiments to figure out and make decisions on how you want to make your electromagnetic arms.

Not only were the students informed about the design challenge, but they were also asked to test the coils to optimize the electromagnet. As shown in the examples above, client letters were used to situate student learning throughout this problem-scoping phase.

Client Needs Were Addressed Through Reminders

Another way that the teacher used the client letter in her instruction was to remind students of the context for learning. On Day 2, the client memo stated, "Today, we would like you [students] to begin to investigate electromagnets. You need to know how they work before designing it. We would like to know what variables in an electromagnet can be changed to change the way it works." Similarly on Day 4, the teacher again reminded students about the client letter they previously received, which asked them to "complete the first control experiment and to test the number of coils in [their] team" to find out which one would work best for their design solution.

For Day 5 and Day 6, context integration was either momentarily present or lacking. While there was no context integration on Day 5, the context integration was brief on Day 6, as students were simply told: "to make the conclusions … [and] report back to *Arcade Inc.* about what you [students] found out because they [client] want to know what your results are." Similarly, on Day 9 and Day 10, context integration was also brief. During both of these days, she revisited the client letter by asking students, "Does *Arcade Inc.* want their game to be won every single time?"

On Day 11, she revisited the client letter and informed students that the client's company wanted another round of tests to determine the best material for their electromagnet. Unlike Day 11, she revisited the design challenge on Day 12 by asking her students to remind the class about what they had to do. In particular, she asked, "Can anyone remind us what *Arcade Inc.* asked us to do?" She then transitioned back into sharing what materials worked best for their electromagnet claw machine and connected them to the client letter by asking "Why did they [client] ask you [students] to test that?"

Communicating Back to the Client

Occasionally throughout the unit, students had to communicate back to the client. This communication was most prominent at the end of the unit, as they had to make a video describing their design, justifying why they chose to build it that way, sharing the results of the test, and mentioning the strengths and weaknesses of the design. They were also asked to engage in evidence-based reasoning (EBR) by including the data from the experiment they conducted. As shown on Day 13, the teacher used the client letter to remind her students about the steps of the design process and the design constraints (i.e., budget). Later on, she asked the students to communicate with the client by creating a video, where they had to describe and justify their design choices. Specifically, she told her students to prepare a filled-out cost sheet, "a total cost …, a chart that shows reasons, [and] the data on what you [students] found" all included in the presentations to the client. This video was presented to the client and shared with others on Day 14, the last day of the integrated STEM unit implementation.

Furthermore, students were asked to collect data and report to the client, describing what they found. On Day 7, she mentioned the client letter again to contextualize and justify why they would engage in variable testing. Students were asked to test certain variables, such as the materials used for wire wrapping, the wire thickness, the number of batteries, the battery voltage, the number of alligator clips, and the length and thickness of the core materials. She asked her students to do their experiments, draw experimental conclusions, and report them to the client. In particular, she informed the students that they would be "responsible for making a data table, you [students] [would] need to make a graph and you [would] need to make some conclusions about what you find."

Content Integration

Content integration happened when Ms. Ashley made connections between different STEM disciplines within the integrated STEM unit. These connections among disciplinary STEM content were either explicit or implicit in nature. Throughout the unit, the teacher made connections between science and engineering; they were often brief and used to inform them about the science content that they had to draw from. She made inferred connections between mathematics and other STEM disciplines, and it was not clear in her instruction why students were learning mathematics to find design solutions.

Explicit Connections between Science and Engineering

Ms. Ashley explicitly connected science and engineering through evidence-based reasoning activities, which took place multiple times throughout the integrated STEM unit. For example, on Day 1, she connected science to engineering by foreshadowing to students that they would need to explain how to make an electromagnet and justify their design. On Day 2, she layered more details into how students would use science content to inform their engineering design decisions by telling the students “to investigate electromagnetism and begin to think about experiments …[which would] help you [students] think about your final design.”

When students were in the planning phase, they were explicitly asked to include an explanation and justification of their designs by drawing on the science data that they produced throughout the unit. For example, on Day 10, the teacher said, “You [students] can use the data from a previous science experiment”.

On the last day of the *Claw Game* unit, Ms. Ashley redirected her students back to the EBR activities by asking them to create a video and share their final designs with the client. Her employment of EBR activities enabled her students to see and understand the connections between science and engineering - mainly how science was utilized for the purpose of engineering. In particular, Ms. Ashley asked her students to use data that they obtained from their scientific investigations as evidence to support their design decisions. This design justification involved asking why they selected certain materials over others during the design planning stage.

Implicit Connections between Mathematics and other STEM disciplines

Implicit connections between mathematics and other STEM disciplines were observed. Mathematics was present in only four lessons from Ms. Ashley’s integrated STEM unit implementation. Its presence was mainly for the purpose of data analysis. For example, students were tasked with calculating and displaying averages of their data.

Specifically, on Day 5, she told her students “We’re just going to graph the average. Okay so here is what we need in a graph.” Students were engaged in graphing as an important tool when working with data collected from their science experiments. On Day 6, she instructed, “You [students] now have data and the graph. Now we need to make the conclusions.” Here, students were expected to use data and information from averaging and graphing as evidence when making claims about their designs. She did not make it clear to students why students need to learn calculating averages and graphing practice would help inform design decisions.

Discussion

In this study, two different ways of STEM integration happened through Ms. Ashley’s teaching instructions: context integration and content integration. Context integration occurred throughout the unit through the use of client letters to situate students’ learning, to help them better understand the EDC, and to provide a more detailed contextualization of the problem. The teacher occasionally used client memos and letters throughout the unit to contextualize students’ learning, either as reminders or as the main lesson content itself. These documents from the client provided a means for Ms. Ashley to remind her students about the client’s needs and how they could apply the science and mathematics content they learned to address the EDC. The client letter was used at the beginning of the lesson (problem-scoping phase) to situate students’ learning by addressing the client’s needs and also later in the lesson while students were communicating with the client. Moreover, the letters were used as part of the main lesson content itself during the problem-scoping and the communicating to the client phases.

Content integration occurs through explicit and implicit connections made between different STEM disciplines. Connections between science and engineering were explicit in Ms. Ashley's instructions. EBR provided an avenue for students to connect science content with the EDC. She asked students to draw on the data they collected and to justify their reasoning by using what they learned from their science lessons. Students were engaged in argumentative practices in an engineering context where they had to use the data, they collected through science experiments to make design decisions.

The connections between mathematics and other STEM disciplines seem weakly connected, meaning they were not made clear to students when it came to the purpose of using mathematics within the unit. Throughout the unit, mathematics was used as a tool for data analysis. For example, students were asked to keep track of budgets for their design solutions, construct graphs of science and/or engineering data, and calculate averages of multiple trials. The implicit integration of mathematics as a tool becomes the norm of STEM classrooms (Walker, 2017; Zhang et al., 2015). It becomes challenging for teachers to engage students in science and/or engineering learning without using mathematical practices, as connections are often not transparent to students. For more desirable learning outcomes, these connections involving mathematics should be made more explicit to students (Honey et al, 2014).

Making connections between STEM disciplines are essential to prepare students for the real world to solve complex problems. When connections are not made transparent to students, then it becomes a problem because students are potentially left to tinker rather than apply science and math knowledge to design solutions. Researchers have found that integrating science, mathematics, and engineering can be challenging for teachers (Guzey et al., 2016; Moore et al., 2014), especially elementary teachers who have limited background knowledge of other STEM disciplines besides science.

In addition to contextualizing learning in real-world problem/engineering design challenge, it is important to make connections between the disciplines and make them explicit to students (English, 2016; NAE & NRC, 2014). Although teachers may understand the connections within an integrated STEM lesson, students often struggle to make connections between STEM disciplines on their own (Dare et al., 2018; Tran & Nathan, 2010). It is critical that teachers must help students recognize and identify these connections or explicitly make these connections visible for students within integrated STEM lessons.

Limitation

While this study provides important information about the ways Ms. Ashley made connections between different STEM disciplines and fills a gap in the literature, there are a few limitations to this study. First, findings are not generalizable to other contexts, given its single case study nature. Furthermore, only transcripts for whole class instruction were available as our primary data source. Because of this, there may have been other instances where teachers made connections between different disciplines during small group discussions, which were not captured by the video camera during recording.

Conclusion and Implications

This case study advances pedagogical understanding of how to teach STEM content in an interdisciplinary manner in K–12 science classrooms. It posits theoretical models of context and content integration across STEM disciplines, and models student learning in a context-rich manner. In this study, a real-world problem is presented as an EDC. The use of an EDC, presented from the client's perspective, provides context for students to learn and engage in learning science and mathematics content. Furthermore, as shown in this study, the use of an EDC engages students in engineering practices, and the EDC serves as a contextual integrator within a STEM unit. Integration through engineering practices engages students in authentic STEM practices that are important to developing a conceptual understanding of STEM (Kelley & Knowles, 2016). Science and mathematics knowledge and application are central to the discipline of engineering and integrated STEM (Moore et al., 2014). Since students learn best when they see how STEM disciplines are connected to one another, elementary science teachers should make these connections explicit and visible to students to help them develop a conceptual understanding of STEM concepts. The findings from this study provide some preliminary guidance on conceptual and contextual integration.

To address the STEM initiatives and policies on a national level, it is important to understand STEM integration at the practice level. This single case study allows several meaningful implications for integrated STEM education to emerge. First, having an understanding of integration at the practice level will allow curriculum developers to better understand how integrated STEM curricula can be implemented in classrooms. Second, by researching the implementation of K–12 engineering standards through STEM integration, this paper adds to the theoretical basis for curriculum development in STEM integration environments where engineering is the key to integration. This case study could be used as an exemplar to show how STEM integration can be implemented in elementary science classrooms and can be important for teacher educators, district administrators, and those involved in creating and facilitating professional development surrounding STEM integration; thus, breaking down the barrier between research and practices. Further large-scale studies related to science teaching practices used in integrated STEM education are needed. As schools are adapting to STEM-focused learning, elementary science teachers need more guidance in integrating STEM disciplines. As such, professional development opportunities should be grounded in integrated STEM models and should provide an example of what integrated STEM instruction looks like in practice.

Chapter 4: Manifestations of Integration into Practice: A Multiple Case Study Exploring Enactment of Three Elementary Science Teachers' Contextual Integration

Recent global educational reforms promote the integration of engineering practices and content into science teaching (NAE & NRC, 2009; NGSS Lead States, 2013). For example, in the United States, the Next Generation Science Standards (NGSS) requires educators to incorporate engineering into their science curriculum, with a focus on science and engineering practices. The integration of engineering brings multiple benefits, including improved success in mathematics and science, heightened awareness of engineering careers, enhanced understanding and application of engineering design, and increased technology literacy (National Academies of Engineering [NAE] & NRC, 2009; Kelley & Knowles, 2016; Moore et al., 2020). Indeed, engineering design offers students a platform to immerse themselves in real-world contexts and authentic problems inherent to engineering (Atman et al., 2007). This engagement serves to underscore the tangible connections between classroom learning and real-world applications (Cunningham and Lachapelle, 2014; Moore et al., 2014; Stohlmann et al., 2012).

With forty-five U.S. states aligning science standards with the Next Generation Science Standards (NGSS, 2013), the focus shifts towards enhancing teaching methodologies, empowering and motivating diverse student populations, and fostering interest and skills crucial for STEM careers (National Research Council [NRC], 2012). Consequently, educators are encouraged to embrace integrative STEM approaches, highlighting the importance of K–12 science teachers understanding integrated STEM education (NGSS Lead States, 2013). While research has explored teachers' implementation of integrated STEM (Aranda et al., 2018; Guzey & Ring-Whalen, 2018; Guzey et al., 2019), limited research has explored the ways in which teachers use engineering as a context to motivate students' learning. Therefore, this study aims to investigate the ways in which three elementary science teachers integrated engineering contexts into their science classrooms. Specifically, this study is guided by the following research questions:

(1) How does context integration manifest in three elementary teachers implementing an integrated STEM unit?

(2) What were the differences observed between their implementations?

Literature Review

A significant challenge in STEM education lies in the lack of consensus among stakeholders on how STEM should be conceptualized and implemented (Dare et al., 2019; Moore et al., 2020; Navy et al., 2021). This ambiguity creates difficulties for teachers, who often struggle to translate these varied conceptions into classroom practices. While there are broadly recognized characteristics of STEM education—such as the inclusion of authentic, real-world problems, the development of 21st-century skills, and the promotion of STEM careers (NAE & NRC, 2014; Roehrig et al., 2021)—many aspects of STEM integration remain less clearly defined, complicating teachers' efforts to effectively implement these practices.

For the purpose of this study, we adopt Roehrig and colleagues' (2021) framework, which identifies seven key characteristics of integrated STEM education: (a) a focus on real-world problems with a central emphasis on engineering, (b) the integration of context to ensure relevance and authenticity, (c) the inclusion of content from multiple disciplines, (d) the use of STEM practices to promote inquiry and problem-solving, (e) the development of twenty-first-century skills, and (f) increasing awareness of STEM careers (Table 4.1).

Table 4.1: Summary of Characteristics of I-STEM

Tenets of Integrated STEM Framework	**Description**
Focus on real-world problems	Real-world problems contextualize and motive leaning (Kelley & Knowles, 2016; Kloser et al., 2018) and engage learner in applying STEM knowledge in proposing solutions (Monson & Besser, 2015).
Centrality of engineering	Real-world problems in integrated STEM education are addressed through EDC, engaging students in authentic engineering practices to develop solutions to complex problems (Cunningham and Lachapelle, 2014; Moore et al., 2014; Stohlmann et al., 2012). This approach fosters engineering thinking and deepens their understanding across STEM disciplines (NRC, 2012; Moore et al., 2020).
Context integration	Context integration in STEM education uses real-world problems or engineering design challenges to make learning meaningful and relevant (Kelley & Knowles, 2016). This approach connects classroom instruction with real-world applications, preparing students for STEM careers through authentic, purpose-driven activities (Cunningham & Lachapelle, 2014; Moore et al., 2014).
Content integration	Content integration in STEM education blends science, technology, engineering, and mathematics to create cohesive learning experiences (Bybee, 2013; Rennie et al., 2012). This approach fosters robust design solutions, enhancing problem-solving skills and deepening understanding of integrated STEM concepts through iterative and reflective processes (Tank et al., 2019).
STEM practices	A key goal of integrated STEM education is to immerse students in the practices used by professionals in STEM fields, helping them understand the nature of the work and the processes involved (Kelley & Knowles, 2016; Moore et al., 2020; Reynante et al., 2020).

Tenets of Integrated STEM Framework	Description
Twenty-first-century skills development	Twenty-first-century skills, such as knowledge construction, real-world problem-solving, creativity, communication, and collaboration, are essential for students to adapt and succeed in the future STEM workforce (Moore, Glancy, et al., 2014; Stehle & Peters-Burton, 2019).
STEM careers awareness	Integrated STEM education immerses students in the authentic work of STEM professionals, offering a deeper understanding of STEM careers by engaging them in real-world skills, processes, and problem-solving strategies (Luo et al., 2021; Ryu et al., 2018).

This framework highlights the importance of engaging students in real-world problem-solving, where science learning is contextualized through real-world scenarios. This perspective not only contextualizes the learning of science but also provides students with a realistic representation of how STEM knowledge is applied beyond K–12 education. Furthermore, it centers on students' interests and needs, making learning more relevant and meaningful as they explore how STEM can impact their lives and future careers. Given the focus on engineering in NGSS, a prevalent approach to integrated STEM is using engineering design as a context for learning (Moore et al., 2014; Bethke et al., 2013). The interdisciplinary nature of engineering underscores the need to apply mathematical and scientific knowledge to address real-world challenges encountered by engineers (Lachapelle & Cunningham, 2014) and provides a valuable opportunity and context for interconnected learning across disciplines (Moore et al., 2014). Research consistently shows that participation in engineering activities enables students to bridge abstract concepts from mathematics and science with real-world applications (Kelley & Knowles, 2016; Kennedy & Odell, 2014; Moore et al., 2014). This approach not only deepens students' comprehension of these subjects but also enhances the relevance and engagement of the learning experience, providing them with the tools to address complex global challenges (Cunningham & Kelly, 2017). The hands-on, problem-solving nature of engineering design experiences inherently motivates students by tapping into their natural curiosity and desire to understand how systems work (Adams et al., 2011; Carlson & Sullivan, 2004; NRC, 2014).

Engineering design challenges are particularly effective in making learning meaningful, as they offer students the opportunity to tackle authentic, real-world problems (Crismond & Adams, 2012; Moore et al., 2020). These challenges require students to apply interdisciplinary knowledge and engage in iterative processes of ideation, testing, and refinement, which mirror the practices of professional engineers (Kelley & Knowles, 2016; Moore et al., 2014) . This method of learning not only enriches the educational experience but also empowers students to see the applicability of their skills beyond the classroom, inspiring them to pursue further studies and careers in STEM fields (Pleasants & Olson, 2019). By integrating engineering into STEM education, educators can create dynamic learning environments that foster creativity, critical thinking, and a strong foundation for future success in a technologically driven world.

Engineering Design

Design is considered the core of engineering, as it embodies the iterative nature of problem-solving and innovation (Dym, 1999). As such, engineering is most commonly integrated into K–12 classrooms through engaging students in the engineering design process. For example, NRC (2012) describes the engineering design process as iterative, beginning with problem identification, considering constraints and criteria for desired outcomes, and concluding with refined solutions. This process involves testing and modifying solutions based on results, leading to optimal outcomes (NRC, 2012).

Engaging students in engineering design also allows them to apply their science and mathematics knowledge in practical, real-world contexts. This approach connects classroom learning to authentic engineering challenges, making it more relevant and meaningful (Bers et al., 2002; Brophy et al., 2008; Cunningham & Lachapelle, 2014; Moore et al., 2014; Stohlmann et al., 2012). When students work through engineering design challenges, they encounter problems that closely resemble those faced by engineers, helping them see how academic knowledge can be applied to solve tangible issues (Kelley & Knowles, 2016; Moore et al., 2020).

Furthermore, these design experiences have been shown to be intrinsically motivating for students, as they tap into their natural curiosity and drive to understand how things work (Adams et al., 2011; Carlson & Sullivan, 2004; NRC, 2014). By engaging in hands-on problem-solving, students develop skills in self-guided inquiry and critical thinking. This mirrors the complex problem-solving processes typical of professional engineering, where trial, error, and iteration are crucial components of finding effective solutions (Crismond, 2001; Cunningham & Hester, 2007; Mehalik et al., 2008; Purzer et al., 2015).

Moreover, incorporating engineering design into STEM education provides an interdisciplinary approach to learning. It helps deepen students’ conceptual understanding in other subject areas, particularly in science. Research has shown that when students engage in design-based activities, they not only develop a better grasp of scientific concepts but also see the practical applications of these concepts in engineering (Kolodner et al., 2003; Mehalik et al., 2008; Bethke Wendell & Rogers, 2013).

Teaching Engineering

Teaching engineering poses unique challenges that distinguish it from other scientific disciplines, largely due to the multifaceted and complex nature of engineering design. According to Wendell et al. (2014), these challenges reflect the intricacies students face when engaging in engineering design, where they must navigate a range of interconnected tasks and considerations (Crismond & Adams, 2012). Engineering design involves not only the technical aspects of creating solutions but also requires a comprehensive understanding of problem definition, integrating the perspectives of clients and stakeholders, addressing specific needs, exploring existing solutions, and working within constraints imposed by both clients and physical limitations (Dym et al., 2005). The process typically includes prototyping and embracing the iterative nature of design, which involves repeated cycles of testing, feedback, and refinement.

The complexity of teaching engineering lies in helping students manage these diverse elements while maintaining a focus on the overall design objectives. Educators must guide students through the entire design process, from initial problem scoping to the final implementation of solutions, emphasizing the importance of iteration and adaptation. This approach not only requires a deep understanding of the technical content but also demands that students develop skills in critical thinking, creativity, and communication. As such, teaching engineering effectively involves fostering an environment where students can explore, experiment, and learn from failure, reflecting the real-world challenges of engineering practice.

Research suggests that integrating engineering contexts throughout an entire unit, rather than merely presenting engineering as a culminating project, can significantly enhance student motivation and engagement in both engineering and science learning (Guzey et al., 2016). By embedding engineering tasks within the broader curriculum, students are consistently exposed to the relevance of engineering principles and practices, allowing them to see the connections between what they are learning in the classroom and how it applies to real-world problems (Chao et al., 2017). This continuous integration helps to demystify engineering and makes it more accessible, encouraging students to persist in the face of challenges and to develop a more nuanced understanding of the role of engineering in solving complex issues. By continuously engaging with engineering contexts, students are better equipped to see the interdisciplinary nature of STEM fields and the value of their contributions as emerging problem solvers.

Research highlights the importance of aligning engineering design challenges and real-world problems with specific content-learning objectives to maximize their effectiveness (Roehrig et al., 2021). Without a clear and explicit connection between the context of the activity and the intended learning outcomes, students may struggle to see the relevance of the task or fail to grasp the underlying concepts being taught. Therefore, this study aims to contribute to the literature by examining how teachers implement integrated STEM units that incorporate engineering design challenges, with a particular focus on context integration.

Context Integration

Effective context integration in integrated STEM ensures students are not simply participating in hands-on activities but are actively applying STEM principles and content to solve real-world problems (Pleasants et al., 2021). This integration involves crafting scenarios that require the use of scientific, mathematical, and engineering concepts, prompting students to develop evidence-based solutions (Roehrig et al., 2021). When thoughtfully designed, these contexts encourage purposeful engagement with STEM content, enhancing students' abilities to make informed design decisions (Kelley & Knowles, 2016; Kloser et al., 2018; Moore et al., 2020).

Research indicates that without deliberate and explicit connections between the problem context and the intended learning objectives, engineering design tasks can devolve into superficial activities. In these cases, tasks may resemble crafting or trial-and-error tinkering rather than fostering deep engagement with STEM content (McComas & Burgin, 2020; Moore, Glancy, et al., 2014; Roehrig et al., 2021). Students may focus only on surface-level aspects like aesthetics or basic functionality, neglecting the underlying scientific or mathematical principles. To prevent this, STEM activities must be designed with clear criteria and constraints that compel students to apply their STEM knowledge meaningfully, ensuring the context serves as a bridge to learning rather than a distraction (Lachapelle & Cunningham, 2014). It is critical that the engineering design challenge provides a context through which students engage with and understand targeted STEM content. Explicit connections between the context and the content learning goals are essential, as without such connections, design challenges risk becoming mere exercises in tinkering, lacking the depth needed to reinforce STEM learning outcomes (Roehrig et al., 2021).

Methods

An exploratory multiple case study (Yin, 2004) was employed in this study to examine how three elementary teachers engaged in context integration, using an engineering design challenge to motivate and teach science content. This method was selected because of the desire for in-depth exploration (Yin, 2014). Each of the three teachers in this study represented one case, with the phenomenon of study being each teacher's practices and enactment of context integration in the integrated STEM unit. A multiple-case study design provides detailed descriptions and interpretations of teachers' implementation, and by examining multiple cases, this information provides a broader description of their enactment relating to STEM integration. Although the nature of case studies limits the generalizability of the results, this qualitative research design was selected because it allowed in-depth exploration of an integrated STEM unit implementation (Yin, 2014). Once individual cases were analyzed, the cross-case analysis allowed for comparing differences in enacting an integrated STEM curriculum.

Context

This study is part of a larger grant project that engaged approximately 120 science teachers (grades 4-9) in a three-week summer professional development program, totaling over 84 hours, conducted in the Midwestern United States. The project, a collaboration with local districts, aimed to advance K–12 integrated STEM education by utilizing both a STEM integration framework (Moore et al., 2014a) and a framework for quality K–12 engineering education (Moore et al., 2014b). During the program, participating teachers attended a summer institute spanning three weeks dedicated to exploring innovative teaching approaches in engineering and data analysis, integrating engineering principles into science education, and crafting integrated STEM curricula. Within this initiative, teachers collaborated in teams of two to three to develop an integrated STEM unit for their own classrooms, they were supported by a STEM education graduate student acting as a curriculum development partner and instructional coach. They piloted these units with students during a university-based summer camp, refined the curricula based on pilot outcomes, and subsequently implemented the revised units with their students during the following academic year.

This study specifically concentrates on the implementation of a single curricular unit, chosen through purposive, criterion-based sampling (Miles et al., 2013) due to its comprehensive inclusion of all six principles of integrated STEM instruction (Moore, Stohlmann et al., 2014). The unit was collaboratively authored during the project's third year by a team of three elementary teachers.

Participants

The three teacher participants involved in this study were all elementary science teachers. The participants involved in this study were all elementary science specialists. The participants were Ashley, Helen, and Mindy (pseudonyms), all of whom were white female teachers. Their backgrounds are described below and summarized with school demographics in Table 4.2.

Table 4.2: Demographic Information

Teacher	**Setting**	**Students of Color**	**% Free & Reduced Lunch**	**Teacher**	**Setting**
Ashley	Urban	>87%	81%	5th	50 min.
Helen	Urban	92%	93%	5th	50 min.
Mindy	Suburban	28%	20%	5th	60 min.

Note: Teacher names are pseudonyms.

Ashley

Ms. Ashley had less than five years of teaching experience. She worked at an urban Midwestern elementary school where she was the science specialist in her school. She taught science to students from multiple homerooms and grade levels. The school consists of a diverse student population. More than 87% of the students at this school were students of color. Furthermore, more than half of the students at this school were English language learners, and over 70% had access to free and reduced lunch.

Helen

Ms. Helen had less than five years of teaching experience. Helen was the sole science specialist in her school, teaching students from multiple homerooms and grade levels. More than 90% of the students at this school were students of color. Furthermore, more than half of the students at this school were English language learners, and over 90% had access to free and reduced lunch.

Mindy

Ms. Mindy is a white female teacher in this study, and she taught in a suburb of the Midwestern city. She had less than five years of teaching experience when data was collected. Mindy was the sole science specialist in her school, and she taught science to multiple homerooms and grade levels. 28% of the students at this school were students of color. Furthermore, 20% had access to free and reduced lunch.

Curricular Context

The three teachers co-designed and implemented the same integrated STEM unit called *Claw Game*. This curriculum focused on scientific concepts related to electromagnetism. The unit comprised seven distinct lessons (see Table 4.3), each intended to take at least one 50-minute class period. Student learning was contextualized through an engineering design challenge (EDC). Students designed and tested an electromagnetic claw for an arcade game. The client letter introduced the students from *Arcade Inc.* to introduce the engineering design challenge (see Table 4.4). The client letter included a given a set of criteria and constraints that needed to be addressed in the students' proposed designs (Table 4.5) Students were tasked with designing a new electromagnetic claw game arm attachment and communicating their final designs to the client by creating and presenting a presentation that included their designs and evidence-based reasoning. Additional client letters and memos were provided to students throughout the unit (see Appendix).

Table 4.3: Lesson Summary of The Claw Game

Lesson	**Lesson summary**
1	**Problem-Scoping:** At the beginning of the lesson, students are introduced to the client and the engineering design challenge (EDC) via a client letter. They review the engineering design process, engage in problem-scoping, and learn the criteria and constraints from the client letter.
2	**Science Investigation:** In this lesson, students learn background information on magnets and magnetic materials. Students investigate different aspects of electromagnets that affect the strength of the electromagnet. They identify and select a variable to test in the following lesson.
3	**Science Investigation:** In this lesson, students investigate different aspects of electromagnets that impact how magnets work. Students work in their small groups to experiment, testing how the number of coils affects electromagnet strength. They graph their data and write claims supported by evidence about the effect of coils on electromagnets.

Lesson	Lesson summary
4	**Science Investigation:** In this lesson, students conduct experiments to test variables that affect the strength of an electromagnet. They identify patterns in their data and create a poster to share their experimental results with the class.
5	**Plan and Design:** In this lesson, each team of students chooses another variable to test. They then collect data and create visual displays to look for patterns in their data. Students design and build a prototype electromagnet for the client using the information they have learned about electromagnets. They then test their design to see how many washers it can pick up, learn about other groups' designs, and reflect on ways to improve.
6	**Science Investigation:** In this lesson, students are introduced to a new client's need for a "tag" material to be placed on the toys in the game. They investigate which materials are magnetic and recommend the "tag" material to the client.
7	**Redesign and Communication with the Client**: In this lesson, students redesign and retest their new designs based on a new set of criteria and constraints introduced by the client in the previous lesson. They then make a presentation to share their best design with the client, describing the results of their tests and the reasoning behind their design choices.

Table 4.4: Client Letter

First Client Letter
"My company, Arcade Inc., has a problem. We design and build arcade games, and one of the longest and best games is the claw game Diggin' for Fools' Gold. For some reason, people are losing interest in the game and aren't playing it as much. I've attached a news article about claw games, which explains a little about why. We need to figure out how to get people interested in our game again. Can you help us?"

Table 4.5: Criteria and Constraints

Criteria	Constraints
The prototype should be an electromagnet that can be attached to an arm, not a claw	The users can win some of the time, but only sometimes.
Justifying design decisions using data	Only provided materials should be used.
Explaining the design	Limited time provided: one class period to plan the prototype design and one class period to create a prototype

Data Collection

Each day of the Claw Game curriculum was observed and video-recorded, associated lesson materials and field notes were also collected. A total of 39 observations were conducted; Ms. Ashley and Ms. Helen implemented the unit across 14 days, while Ms. Mindy's implementation was 12 days long. Due to a technical error, no recording or field notes were obtained for Day 8 of Ashley's integrated STEM unit implementation. Additional data sources included memos written by researchers while watching implementation videos.

Data Analysis

This study involved three science teachers as individual cases, with the primary focus on examining their implementation of an integrated STEM curriculum. Each case was initially analyzed independently to capture the nuances of each teacher's approach to context integration. Following this, a cross-case analysis was conducted to compare and contrast the teachers' implementation strategies, allowing for a deeper understanding of how integrated STEM education was enacted in different classroom settings.

For the analysis, the author, along with a graduate student, organized the transcripts systematically, ensuring a clear and structured approach to data examination. A deductive coding method was employed, guided by a codebook developed based on the frameworks established by Roehrig and colleagues (2021) (see Table 4.6). This approach provided a consistent and theory-driven structure to the coding process, allowing the researchers to apply predefined codes to the data as recommended by qualitative analysis methodologies (Berg, 2001).

Table 4.6: Code for Context Integration [CXI]

Codes	Codes Description
Problem Scoping	When the teacher used client letters to contextualize learning by unpacking the identity of the client, the client's need, solutions to solve the problem.
Doing Science for Design Challenge	When a teacher makes the connections between the science content with the design challenge.
Communicating with the Client	When the teacher uses the client letter to communicate with the students, and when students communicate with the client, sharing their findings and results.
Contextualizing STEM Career	When the teacher contextualized engineering careers by highlighting the roles of engineers, scientists, and other STEM professionals,
Contextualizing STEM Career	When a teacher makes literacy connections in STEM lessons by integrating vocabulary development, reading comprehension, and writing.

Each transcript was read and coded individually, and the assigned codes were subsequently reviewed in collaborative sessions between the author and the graduate student. These discussions served to identify any agreements or discrepancies in the coding, ensuring reliability and consistency in the interpretation of the data. This iterative process allowed for the refinement of codes and alignment of the researchers' understanding, enhancing the validity of the findings. Codes were consistently applied across multiple days of implementation for each teacher, highlighting patterns and variations in how each teacher engaged with and delivered the integrated STEM curriculum. By repeating the coding process across different days and contexts, the analysis provided a comprehensive view of each teacher's implementation, capturing both the challenges and successes they experienced.

In the final phase of the analysis, the researchers conducted a cross-case analysis, as outlined by Yin (2014), to investigate the variations in how individual teachers enacted the integrated STEM curriculum. This phase aimed to uncover the nuanced differences in each teacher's approach, focusing specifically on how they incorporated contextual integration within the STEM units. The cross-case analysis was grounded in detailed comparisons of the individual units of analysis—each teacher's implementation of the curriculum. By systematically comparing these cases, the researchers were able to identify distinct patterns and divergences in the teachers' instructional strategies. This comparative approach provided a comprehensive view of the range of practices used by the teachers, highlighting how each adapted the curriculum to fit their unique classroom context and student needs.

To ensure the findings were robust and reflective of the data, the researchers relied on rich, illustrative examples drawn directly from the transcripts and other collected materials. These examples not only substantiated the identified differences but also added depth to the analysis, offering a vivid portrayal of each teacher's enactment.

The detailed comparisons across cases revealed variations in how teachers navigated contextual integration.

This cross-case exploration allowed the researchers to move beyond individual case findings and develop a broader understanding of how contextual factors influenced the implementation of integrated STEM education. By examining these differences, the study provided valuable insights into the diverse ways teachers approach context integration, highlighting both the flexibility of the curriculum and the critical role of teacher interpretation and adaptation of integrated STEM curriculum.

Findings

The findings of this study are presented first as individual cases of teachers' implementation of the *Improving the Mechanical Claw* unit. The cases are organized by lesson (see Table 4.3). The data analysis focused on teachers' discourse related to how they contextualized learning; thus, the data provided in each case primarily quotes from the three teachers, with some student discourse to understand the teachers' discourse in relation to the instruction. The cross-case analysis follows the individual case presentation and analysis.

Case 1: Ms. Ashley's Implementation of Integrated STEM

Ms. Ashley's overall implementation followed the flow of the written curriculum (see Table 4.3) using the client, *Arcade Inc.*, to provide context for learning. Her lessons had an overall flow that guided students' thinking to follow the storyline created by the design challenge. Following the curriculum, the client communicated with the students each lesson through a client letter or memo to maintain the storyline and contextualization of the learning through the EDC. Thus, even if a lesson was primarily focused on science and/or mathematics content, the context of the EDC was still maintained.

Lesson 1

In the first lesson (Day 1), students were introduced to the EDC through the client letter (Table 4.4), which identified the design challenge and associated criteria and constraints. Ms. Ashley introduced the lesson by saying,

> *Arcade Inc.* wrote a letter to you. Our goal for today is to figure out who wants what and why. Through this unit, you will learn about the engineering design process and the different steps.

Immediately, Mr. Ashley set up her students to understand that they had been given a challenge and were working with the client. As she started the lesson, she read the client's letter to help students understand what the client was asking them to do, and once she finished reading the client's letter, she asked students a clarification question:

> T: What are we making?
>
> S: Making a claw game with an electromagnet arm.
>
> T: Good, you're making a claw game with an electromagnet arm.

She instructed the students to read the client letter independently, encouraging them to underline or circle important information relevant to their design project as she distributed the letter. Allowing some time for individual reading and highlighting, she then prompted the students to work in groups, discussing and identifying key points from the client's letter. After the initial reading and group discussions, she encouraged students to engage in collaborative brainstorming to determine the company's specific needs for their project. Each group was given a few minutes to exchange ideas and come up with potential solutions based on the information gathered from the client's letter. When students were done collaborating, she gathered them and had the following dialogue:

T: Who needs something? Who is asking you to do this?

S1: President of *Arcade Inc*.

T: What does the president want?

S2: Wants us to make an electromagnet arm.

T: If the claw game already exists and has the claw, why does he want you to make the arm?

S3: The customers don't like the claw game because they think they will never win, and the company is not getting any money and wants to improve it.

S4: The game is rigged, and they want to make more money.

T: If someone has the company, that makes sense if they want to make money.

Ms. Ashley's concise questioning facilitated the students' understanding of who required assistance, their specific requirements, and the necessity to design an electromagnet arm. This approach allowed students to respond to the questions and incorporate relevant vocabulary simultaneously (e.g., "client," "claw," and "fair").

Her inquiry into why the company needed to develop an arm for a claw game highlighted the inherent unfairness and rigging of the game, where customers were unable to win. Ms. Ashley further encouraged students to seek clarification by asking probing questions to grasp the context of the problem. In the subsequent segment, she guided the students through problem scoping, elucidating the concept of a rigged game.

T: To play the game, you need to keep inserting the money in the machine, then the machine saves money in the box, and the company collects it later.

S5: When people can’t win, they don’t want to waste their money.

T: Yes, people don’t play because it’s rigged. Does anyone know what rigged means?

S6: Someone messed it up, and it’s not working anymore.

S7: The company didn’t make it the right way on purpose.

T: Can you explain more about that?

S7: They made it unfair on purpose.

Later in Lesson 1, she introduced an article (see Appendix), as mentioned in the curriculum, that addressed the concept of being rigged. She provided students with ten minutes to read the article in groups. Ms. Ashley summarized the article on how games are being programmed by saying:

> The company designs their claw game only to be strong enough to grab prizes some of the time. Often, players find that even when they’ve aimed well, the claw fails to secure the prize. Winning becomes a rare occurrence, with odds of success only being 5 out of 10, 2 out of 10, depending on how the game is programmed.

She explained the illusion that the game relies on player skill, as they control the claw’s movements. However, the reality is that the game is intentionally programmed to lower the chances of winning. Through this explanation, Ms. Ashley illuminated how companies manipulate game outcomes for financial gain, underscoring the importance of understanding the underlying mechanics behind seemingly chance-based activities.

In this lesson, Ms. Ashley also contextualized the job of STEM professionals for students. She began the unit by introducing the concept of norms, explaining like engineers, students should work together with respect, start on time, and ask questions. She stated,

> Whenever we work in a group, we must keep in mind that we all come from different backgrounds, families, and cultures, and different things are expected of us, but when we work in a group, we work around norms like engineers work together.

Furthermore, Ms. Ashley also emphasized the importance of maintaining notebooks by stating, “All engineers and scientists keep a notebook to document their daily activities. This helps them know exactly when they did something.” Drawing parallels with the practices of professionals in engineering and science fields, she encouraged students to adopt the habit of documenting their work, highlighting its commonality among these professionals as well as contextualizing their task as being aligned with the work of engineers.

Lesson 2

This lesson lasted for one day (Day 2). In this lesson, the client conveyed their requirements through a new client letter, specifying their interest in having students explore electromagnets and devise experiments to inform their final design (see Appendix). Ms. Ashley started this lesson by stating,

> Today, in order to figure out how an electromagnet works, we’re going to find out what we need to do. This is a memo from the client, and it’s coming to you from people you might hear about. It says electromagnet investigation.

Upon communicating the client’s objectives by reading the new client letter, Ms. Ashley promptly prompted the students: “Remember, you’re designing an electromagnet, right?” Throughout lesson 2, Ms. Ashley frequently prompted them with questions such as “Who is the client?” “Who needs our help?” or “Who wrote the letter?” This served to maintain the storyline and the client as the motivation for learning. Throughout the lesson, Ms. Ashley also consistently reinforced the connection between scientific concepts and the design challenge, reminding students of their task to design an electromagnet. She reiterated, “Remember, you’re designing an electromagnet, right?”

After the students explored variables affecting electromagnet strength, Ms. Ashley concluded the activity by prompting them to consider their upcoming task of designing an electromagnetic arm. She urged them to brainstorm within their groups, focusing on potential modifications to enhance their electromagnets. Ms. Ashley specifically made the connection to the context, stating,

> Think with your group about what you could change about your electromagnets. Think about the wires, the nails, the alligator clips, the switch, and the battery. Think about those things and all the materials. What could you change about them that’d help you pick up more washers?

Through this question, Ms. Ashley encouraged the practical application of the science learning that would follow in lesson 3 in order to address the client’s needs.

Lesson 3

This lesson lasted for one day (Day 3). In this lesson, students investigated different variables that impact the strength of an electromagnet. Through this investigation, students were to compile a comprehensive catalog of specific variables they believed could influence the electromagnet’s strength or operational efficiency. Ms.

Ashley initiated the lesson by linking it to the preceding one, wherein students engaged in brainstorming sessions regarding these variables. She refreshed their memories, stating,

> The last time you were here, the instruction that we got from *Arcade Inc.* was for you to play with an electromagnet and come up with a list of things you can change about the electromagnet that'd impact the number of washers it could pick up.

She emphasized the relevance of the upcoming activity to the client by stating,

> The question we're going to investigate today is what an electromagnet is and how we can make it stronger. In order to do what they're [Client] asking us to do, the memo is saying that you'll be testing one of those things from your list.

Throughout the lesson, Ms. Ashley consistently emphasized the integration of context for her students. For instance,

> T: They [the company] really like your list of things they can change.
>
> S1: Who's they?
>
> T: The company. As part of this unit, they hire engineers for *Arcade Inc.*
>
> T: You'll be creating a new attachment electromagnet arm for the claw game. You need to do some experiments to investigate electromagnets and find out how you can make one. Right now, you'll be doing some experiments to figure out and make decisions on how you want to make your electromagnetic arms.
>
> T: Can anyone remember what I told you about the company that we're changing?
>
> T: You'll be designing a claw game, but what will you be changing in this specific electromagnet experiment?

S2: Variables.

Ms. Ashley's frequent references to the client and their requirements helped students to remain aware of the EDC context driving the content learning objectives. When students sought clarification, she promptly reiterated the connection to the client, reinforcing the practical application of their tasks.

Lesson 4

Ms. Ashley commenced the lesson lasted for one day (Day 4) by presenting a new client memo (see Appendix),

> This is the memo. It says we [the client] were impressed with the work you completed yesterday. We'd like you to continue that work by completing the first control experiment testing the number of coils in your team.

By initiating this message, she established a structure where the client's voice permeated throughout the session, emphasizing the importance of aligning with the client's needs. This approach guided students to understand that their experiments were purposeful actions driven by ongoing communication with the client rather than arbitrary endeavors.

While outlining the client's directives, Ms. Ashley specified, "We [the client] need you to collect that data and report back your findings in two to three sentences." Immediately afterward, she prompted the students:

T: I'll give you a minute to discuss: Where are we in the EDP?

S: Learning.

> T: What questions are we trying to answer with our experiment? Right now, we're engaged in background research, so later, when you plan and create your electromagnetic lever.

This approach linked the design challenge to the engineering design process, ensuring that students comprehended their current stage in developing the electromagnet arm.

The interaction between the students and the client was reciprocal. Ms. Ashley prompted the students with a question,

> How does the number of coil wires affect the number of washers the electromagnet picks up? That's what the client asks you to test. You're [students] going to answer those questions when you report back to the client.

This underscored the students' responsibility to not only conduct experiments but also to communicate their findings to the client.

Lesson 5

Over the course of three days (Days 5, 6, and 7), students collaborated in teams to select and test variables. They collected data by experimenting with various values of the chosen variable and subsequently constructed graphs to represent their findings. However, on Day 5, she did not incorporate any contextual connections or integration into the lesson.

On Day 6, Ms. Ashley started the lesson by stressing the importance of reporting their findings to the client, stating,

> You now have data and a graph. Now, we need to draw conclusions so we can report your discoveries to the client because they are eager to learn about your results. It's essential to formulate a conclusion based on your data and graph.

> Then, we can communicate our findings to the client. They are keen to understand the outcomes of your experiments. To achieve this, we will make a claim supported by evidence.

This reiterated the significance of not only conducting experiments but also communicating the results effectively to the client.

As students delved into formulating claims supported by evidence, Ms. Ashley emphasized the utilization of both their data tables and graphs. She underscored the fundamental principle of scientific inquiry, highlighting the significance of leveraging data and graphical representations. Furthermore, Ms. Ashley reinforced the connection between their scientific inquiry and the client's needs:

> T: Do you remember what a variable is?
>
> S: A variable is anything that we can change in an experiment.
>
> T: With ten coils, we picked an average number of washers. Underneath your claim and evidence, I want you to write to *"Arcade Inc."* what you found out.

On Day 7, Ms. Ashley started by referencing the previous lesson,

> Last time, we concluded by communicating our findings to the client. It's evident that the client values your assistance. Here's the latest memo from them; they've reviewed our report. Each group is now tasked with conducting another controlled experiment to gather additional data on electromagnets.

In this way, she briefly tied the current task to the ongoing client engagement while introducing the new instructions from the client. Ms. Ashley clarified the specific constraints of the design challenge, stating,

> We’ve received feedback from our client regarding your initial report. They’ve requested that each group conduct an additional controlled experiment to gather more comprehensive data on electromagnets.

Expanding on the client’s directives, she explained that the client specifically outlined five materials they wanted to be tested. These included variations in wire wrapping, referred to as gauge, and the impact of using multiple batteries. Ms. Ashley elaborated that the client was particularly interested in examining the effects of increasing battery quantity, including testing with different sizes of batteries provided for this purpose.

Lesson 6

During the three days of this lesson (Days 9, 10, and 11), students were tasked with designing and constructing a prototype of an electromagnetic claw arm for their client. They put their designs to the test by repeatedly attempting to lift and transfer a small toy attached to a washer from one container to another. Following these trials, students utilized the data gathered to justify their design choices.

On Day 9, as they commenced their work, Ms. Ashley directed their attention to the necessity of utilizing information about electromagnets for their design process. She emphasized the importance of comprehending the workings of electromagnets, as this understanding would be crucial in crafting their electromagnet arms during the planning stage. As the lesson progressed, Ms. Ashley prompted the students,

> Along with the detailed picture of your design, provide a justification for each of the decisions you make. Does the client want their game to be won every single time? They would lose money if it’s too easy.

In this way, she conveyed the importance of not only presenting comprehensive design visuals but also justifying their choices and attending to the context of the game being rigged. By posing the question about the client's objectives, she encouraged students to delve deeper into the problem by considering the client's perspective. She also ensured clarity in their understanding of the project requirements.

On Day 10, Ms. Ashley reiterated a new constraint imposed by the client. She contextualized the limitation by framing it through the lens of the client's perspective, stating,

> They [client] said we can only give them [students] three batteries because we don't have enough space in the actual room on the sheet when we scale it up to make it bigger. We don't have enough space to have more than three batteries. So, no more than three.

On Day 11, as students were testing, Ms. Ashley engaged in a dialogue with the students about the merits of their electromagnet designs:

> T: Write down a couple of things about why your electromagnet was a good solution. What else did you do?
>
> S1: I tested it out.
>
> T: Yes, we tested it out.
>
> T: How well did your electromagnet pick up the washers?
>
> S2: It picked up.
>
> T: Did you build your electromagnet last time?
>
> S2: Yeah.

T: So you did the try where you were building it and then tested it. Then I asked you to write two sentences about why you think it's a good solution for the company.

In this interaction, Ms. Ashley guided the students to reflect on their design process and articulate why their solution would be advantageous for the client company, reinforcing the connection between their experiments and the needs of the client. Another example illustrated how Ms. Ashley prompted the students about the design choices:

T: What did we do last time? Can anyone remind us what the client asks us to do?

S1: Materials used for claw machine.

T: To see what materials we can use for the claw machine. Why did they [Client] ask you to test that?

S2: To see if the electromagnet was strong or not.

S3: To see what materials were best for the design.

T: Do you know what materials you would be putting on?

In this exchange, Ms. Ashley guided the students to reflect on the purpose of testing materials for the claw machine and encouraged them to consider potential choices for their client's design.

Lesson 7

This lesson lasted for three days (Day 12, 13, and 14). In the final lesson, students focused on redesigning and effectively communicating their solutions and findings to the client. Under Ms. Ashley's guidance, they were reminded of the significance of including comprehensive details such as experimental procedures, data tables, and graphs in their reports. The communication process involved providing updates on experiment results, receiving feedback from the client on reports, and addressing additional tasks like furnishing detailed pictures of their designs along with justifications.

On Day 12, Ms. Ashley introduced a new client memo (see Appendix). She asked students:

T: What did we do last time? Can anyone remind us what the client asks us to do?

S1: Materials used for claw machine

T: To see what materials we can use for the claw machine.

T: Why did they ask you to test that?

S2: To see if the electromagnet was strong or not.

T: I wanted to see what materials were best for the design. Do you know what materials you would be using?

T: What changes are you going to make?

On Days 13 and 14, Ms. Ashley directed the students' focus toward preparing their video presentation for the client. Encouraging them to articulate the advantages of their electromagnet solution for the company, she prompted them to integrate elements such as testing outcomes and reasoned justifications. She emphasized,

> You need to have your electromagnet set up right so that you can demonstrate how it works on your video. You need to have your task sheet filled out with a total cost down somewhere below. You need to have your form chart filled out here with the reasons that you picked everything.

Ms. Ashley emphasized the importance of adding depth to their communication with the client by providing thorough justifications for their choices.

Case 2: Ms. Helen's Implementation of Integrated STEM

Ms. Helen's overall implementation followed the flow of the written curriculum (see Table 4.3) leveraging the context provided by the client, Arcade Inc., to contextualize the learning. Her lessons had an overall flow that guided students' thinking to follow the storyline created by the design challenge. Following the curriculum, the client communicated with the students each lesson through a client letter or memo to maintain the storyline and contextualization of the learning through the EDC. Thus, even if a lesson was primarily focused on science and/or mathematics content, the context of the EDC was still maintained.

Lesson 1

This lesson consisted of one day (Day 1). Ms. Helen kicked off the unit with a focus on engineering, setting the stage with the introduction of a client letter that framed the unit (see Table 4.4). Ms. Helen enthusiastically announced to the class, "We are going to be starting our engineering project today." She conveyed to the students, "We're going to try to get through a lot of information right now in a short amount of time and figure out what our engineering problem is today by reading a letter from the client." As the lesson progressed, Ms. Helen encouraged student participation by assigning them to take turns reading the client's letter aloud. She facilitated discussion by posing questions that helped the students to understand the context of the EDC, such as:

T: What does it mean to be rigged?

S1: Somebody changes the game.

T: Somebody kind of changes the game. What else might it mean?

S2: So that nobody can win.

T: It’s made that way that nobody can win.

Ms. Helen integrated literacy into the lesson, dedicating substantial time to reading and discussing the client letter with her students. This approach clarified key concepts like the role of a client and introduced relevant vocabulary such as prototype and rigged.

Ms. Helen guided the students in problem scoping by prompting them to identify the needs of the client. She emphasized this by stating, “You will receive daily memos from the various engineering teams that are working on this project. The memos will instruct you on what your daily tasks will be.” She clarified who the client was by saying,

> Thank you for your consideration from Orion Nova, the president of the Arcade Inc. I want you to talk about who we are helping, what we’re doing, and why they want us to do it. Focus on who, what, and why.

During problem-scoping, she directed the students to concentrate on understanding who was commissioning the project, what actions were required, and the underlying purpose. This approach aimed to clarify the identity of the client and the objectives of the project task.

Ms. Helen organized the students into teams and instructed them to thoroughly examine the client letters for relevant information. Throughout this process, she posed questions such as:

T: Do you agree with the other group? Are we working for the Arcade Inc.?

S3: Yes.

T: Who’s the president of the company?

S3: Orian Nova.

> T: Oh, he’s like your boss right now. You need to follow his directions because, in the end, as an engineer, he’s going to pay you.
>
> T: What does Arcade Inc. give you to do?
>
> S4: Make a new claw.
>
> T: Why does Arcade Inc. want us to build a new claw?
>
> S5: Because the machine is not working.
>
> T: Specifically, it’s rigged.

Through her questioning, Ms. Helen clarified the client’s needs and expectations to the students. She underscored the importance of Orion Nova, the company president, as the client and emphasized the necessity of adhering to his instructions. Furthermore, she delved into understanding why a new claw was required, particularly due to the issue of the existing machine being rigged.

Ms. Helen introduced the concept of the rigged claw game by sharing an article as outlined in the curriculum. She acknowledged the time constraints by not reading in groups, stating, “You [students] have an article, but I’ll read it kind of quickly, too, because we don’t have time to read the whole thing.”

Although the students didn’t spend much time on the article, Ms. Helen connected its content to the problem:

> Arcade Inc. wants us to create a game that’s kind of easy, kind of hard, and you have to be good at it. Right now, it’s like, oh, you might be good at the game, but they’re not gonna let you win because they can make the claw really weak or really strong. So they get to pick how strong it is. You don’t know; you don’t

> have to be good at losing no matter what, so we need to create a new claw that's going to show you how good you are at the game.

As students finished the rigged article discussion, she instructed them to write in words the who, what, and why they are helping the client in their groups. This approach encouraged students to articulate their understanding of the client's needs and the purpose behind their assistance.

Lesson 2

This lesson consisted of one day (Day 2). Ms. Helen began the lesson by linking to the previous day's activities, stating, "Yesterday, we started our engineering design challenge. Very quickly, let's review the who, what, and why. So, think back to the client letter we read yesterday. Raise your hand if you remember." This brief review served to illustrate the continuity of both the context and learning from the previous day.

Ms. Helen reinforced the company's name, stating, "If you don't remember the company name, it's Arcade Inc." She further emphasized the task at hand, instructing, "And what the company is asking us to do is to make a new claw so customers will play your games." Communicating the client's needs as outlined in the client's letter (see Appendix), she stated, "We [the client] would like to give the contract to develop a prototype of an electromagnetic arm that will be used instead of the claw." She then prompted students to reflect on the purpose behind the task, asking, "So, what are we replacing the claw with? And why did they want us to do this? Today, why are we doing this again? Why? Why did we want to build a new claw?" Ms. Helen clarified that the students were oriented to the company's name and understood the task assigned to them. She also stressed the importance of addressing the client's needs throughout that day.

Again, Ms. Helen integrated literacy as she continued this lesson by explaining to students what “rigged” means. She stated,

> So because the current game is rigged, we want it to be fairer. Right now. It’s not fair. Yeah, some people, even if you’re good at the game, they are not going to win because the game doesn’t allow them to win.

Ms. Helen introduced the students to a mini claw game toy and encouraged them to engage with it. She explained,

> This is a claw game, and the ones in stores are tough to win. We’re going to compare it to this one. So, I’m going to choose someone who will get to play it today. And if you win, you’ll get to keep one of the prizes you grab. Hopefully, everyone will have a chance to play the game.

By providing students with the opportunity to play the mini claw game, Ms. Helen allowed them to experience firsthand what it feels like to interact with a real claw game, facilitating tangible connections with the concepts being discussed. Engaging students in the claw mini-game also allowed Ms. Helen to delve deeper into the considerations involved in owning a claw machine and how to decide on prize distribution. She engaged the students by asking:

> T: Can I ask why you own the claw game? The purpose of having a claw game?
>
> T: Would you want it to be able to give three or four prizes to somebody?
>
> S1: No, you want them to win maybe one prize if they’re good at it.
>
> T: Who pays for all the prizes here, and who owns the machine? So, do I want to give away all my prizes?
>
> S2: No, because they want to make money off it.

T: People still want to be able to make money off their machines. So we have to make sure it's not too easy like this one but not too hard like the other ones.

In this manner, Ms. Helen illustrated to the students that as proprietors of a claw machine, they bear the responsibility of covering the expenses for all the prizes claimed by players. This method elucidated to the students the user's standpoint, the economic factors entailed in managing a claw machine, and the balance required to ensure profitability while maintaining player engagement.

As the lesson progressed, Ms. Helen introduced the client's latest request by displaying a new memo on the projector and prompting students to read aloud that they would be investigating electromagnets and planning an experiment. She emphasized, "So we're going to try to finish it now so we can catch up to where we're supposed to be based on what our boss [client] is telling us." She instructed students to include the written title, date, and question at the top of their notebooks. She informed them that they would be examining a picture of an electromagnet and jotting down their observations. Following her instructions, students engaged in the task and focused on making their observations for the rest of the class time.

Lesson 3

This lesson consisted of one day (Day 3). Ms. Helen initiated the class by presenting the question of the day, "How can you change the strength of an electromagnet?" She displayed a diagram of an electromagnet and prompted students to brainstorm variables they could alter. Drawing a connection between the science experiment and the client's needs, she explained, "As long as we have a good list of things we could test about our electromagnet, we received a letter from our boss last night. This morning, I'll read the client's letter to you." By referring to the boss as the client, she highlighted to the students that their experiment could address the needs outlined in the client's letter.

Ms. Helen continued by sharing the client memo that the client was impressed with the student's work. She proceeded with the client letter, stating,

> We have looked through your list, and we'd like you to continue that work. Begin by conducting your first controlled experiment, testing the number of coils in your team's electromagnet. We believe that exploring this variable could yield the most valuable data for your research. Please collect data and report your findings back to us in two to three sentences.

After conveying the client's instructions from the letter, she engaged the students, asking, "What does the memo tell us we need to do today?" She checked with the students on the client's directives and understanding of the project task.

Ms. Helen also briefly connected the lesson with the work of STEM professional, stating, "Scientists create data tables," without elaborating further. These statements were briefly addressed to the students to highlight the practical applications of the skills they were developing in the classroom. Subsequently, students were occupied with conducting their experiments for the remainder of the lesson.

Lesson 4

This lesson consisted of one day (Day 4). Ms. Helen initiated the lesson with a question of the day: "How can you change the strength of an electromagnet?" She then instructed the students, "You received a memo from your boss yesterday reminding you about the coil test. No one has completed it yet. The boss didn't send any memo, and I don’t think he’s very pleased with us. Let’s read it.” She referred to the client memo from the previous lesson to frame the lesson, she also conveyed to the students that the client was currently displeased because the testing had not been completed as requested. She conveyed the client’s displeasure by stating, “We’re still awaiting your report from the coil experiments. As you may remember, we asked you to provide us with your findings in two to three sentences. This must be completed by the end of today.” By setting this deadline, she emphasized the urgency of the client’s request and the importance of meeting their expectations.

She directed students to test another variable from the list provided by the team and report their findings. Stressing the significance of incorporating a data table and graph into the report, she emphasized, “It’s important to include the data table and graph in your report.” For the remainder of the lesson, students were occupied with calculating averages as per her instruction and continued with the coil testing.

Lesson 5

This lesson consisted of three days (Days 5, 6, and 7). Ms. Helen guided students in selecting variables to test, collecting data, and creating tables and visual displays to analyze patterns in the data in this class. On Days 5 and 6, no contextual integration was observed.

On Day 7, Ms. Helen briefly reminded students of the EDC context, stating,

> We were asked to create an electromagnet arm for a claw game that will help make the game less about being rigged and more about how good you are at the game, your skill level. So that means we’re gonna have to design an

> electromagnet that's not going to win all the time but is going to let people win sometimes.

Ms. Helen outlined the task, emphasizing the need to create an electromagnet arm for a claw game that promotes fair play and rewards skill rather than chance. She emphasized the importance of designing an electromagnet that doesn't guarantee victory every time but rather allows players to win based on their abilities.

Ms. Helen underscored the importance of the data collected from the students' science experiments, emphasizing that the insights gained from this data are crucial for making informed adjustments to the various components of their electromagnets. She specifically highlighted how altering variables, such as the number of batteries or the thickness of the wire, could significantly impact the performance of the electromagnet. She explained to the students, saying, "The reason we've been doing all this data research is so that we know how to change each part of the electromagnet to do what you want. So that means we're going to have to share our presentations and share our posters with the whole class so they know what happens if you change the number of batteries, the thickness of the wire."

This approach demonstrated Ms. Helen's effort to emphasize the value of presentations as a tool for peer learning and reflection on experimental results. However, her guidance primarily focused on communicating findings within the classroom context, without extending the discussion to include how students might present their results in a real-world context, such as addressing a client or stakeholder. She did not guide students on how to center their presentations around the needs and perspectives of a client, which would have provided an additional layer of contextual integration and relevance to their work.

Ms. Helen set the stage for the upcoming lesson by foreshadowing the next steps in the unit. She explained,

> T: We'll review our problem one more time and will start to work from the planning stage. So we're still in the background gathering data for everybody. Understand?
>
> S: Yes.
>
> T: Then we'll move into learning so that hopefully, by tomorrow, we can build our designs.

By outlining this sequence, she aimed to link the students' current data collection efforts to the forthcoming engineering design work, highlighting how their findings would inform and support the planning and building phases of their electromagnet designs. She emphasized the importance of this data as a foundational element that would eventually contribute to their design endeavors, helping students understand that their analytical work was not isolated but directly connected to the practical tasks ahead. However, while she made an implicit connection between data collection and the engineering context, Ms. Helen did not explicitly tie these activities to the needs or expectations of a specific client or external stakeholder. This lack of direct reference to the client missed an opportunity to deepen the real-world relevance of the unit.

Lesson 6

This lesson spanned three days (Days 8, 9, and 10), aiming for students to develop and construct a prototype of an electromagnetic claw arm for the client. On Day 8, Ms.

Helen initiated the session by asking the question of the day: “How can we use all of our data to solve our problem?” Following this, she introduced a memo stating,

> Arcade Inc. today says, fantastic work, we’re getting very close to the line, we’ll need each team to come up with a design plan that you can build tomorrow. Along with a detailed picture of your design, you need to provide a justification for each decision you have made.

She shared that the client expressed satisfaction with the progress and emphasized the need for each team to formulate a design plan for construction the following day. In addition to presenting a detailed illustration of their design, students were required to provide a rationale for each decision made. Through this communication, Ms. Helen conveyed the client’s expectations and celebrated the recognition of the student’s efforts by the client.

As students progressed through the lesson, Ms. Helen reminded them of the key points from the client letter in lesson 1 (Table 4.4), emphasizing the necessity of redesigning the claw game to ensure fairness and skill-based outcomes for customers. She directed each team to receive a planning sheet and take turns contributing ideas, including sketching the arm’s design, selecting battery size and quantity, determining wire gauge, deciding on the wrapping material for the wire, specifying the number of coils, and assigning the number of alligator clips.

Ms. Helen emphasized the importance of collaborative work by highlighting that teamwork involves shared responsibility and the cooperative completion of projects. She stressed that effective teamwork requires each member to contribute actively and support the group’s efforts to achieve their goals. By focusing on these aspects, she aimed to instill in students an appreciation for the value of working together in a unified manner. However, while Ms. Helen effectively underscored the general principles of collaboration and teamwork, she did not extend this discussion to help students understand its relevance in the context of engineering or other STEM professions.

On Day 9, no contextual integration was observed. On Day 10, Ms. Helen initiated the lesson by asking students, “Can anyone recall who our client is and what they tasked us with?” She then delved into the importance of determining the optimal strength for the electromagnet, explaining, “Our primary concern with the electromagnet arm is finding the right balance. If it’s too powerful, it’s counterproductive; if it’s too weak, it’s equally problematic. We’re aiming for a middle ground.” Drawing a connection to a recent memo from the client, she conveyed, “We’ve received correspondence from our client data today, indicating that the toy design team is currently developing toys for the game. They’ve requested further testing from us to ascertain the most suitable materials for use with our electromagnet.” The students spent the rest of the period engaged in determining the most suitable toy materials.

Lesson 7

During the four-day span encompassing Days 11 through 14, students focused on redesigning and effectively communicating their solutions and findings to the client. Ms. Helen commenced Day 11 by addressing their ongoing redesign efforts adding, “We were told that we needed to investigate which material would work best. Then, as a group, we were supposed to discuss and decide which material we thought would be most suitable for the toy.” She linked their upcoming work to a recent client correspondence (see Appendix), highlighting the importance of conducting thorough investigations to identify the most suitable materials for the project.

Furthermore, she instructed, “Once your team has refined or designed, create a video presentation based on the guidelines provided by the rubric.” Referencing the evidence-based reasoning sheet, she reminded students about the documentation in their folders from their initial designs, including details such as the number of alligator clips, battery size, quantity of batteries, and wire size. She prompted students to consider their previous decisions.

On Day 12, students focused on creating their video presentations. Ms. Helen provided a brief reminder, emphasizing the importance of including details and justifications for the materials they selected in their designs. No explicit contextual integration was observed.

On Day 13, students remained immersed in refining their video presentations. Ms. Helen asked a probing question: “How does your team plan to approach the redesign of your electromagnet?” She seamlessly connected this inquiry with the progress achieved the previous day, acknowledging, “Yesterday, five out of the six groups successfully completed the construction of their new and improved electromagnet and designer toy. With this significant milestone attained, the groups are now preparing for their final presentations.” She also reminded students about the impending client critique, stating, “The client will evaluate and grade your work based on the criteria.”

On Day 14, the final session of the lesson series, Ms. Helen emphasized the importance of creating video presentations for the client. She briefly stated, “Every group has their materials and has built and tested their electromagnets. Today’s goal is for each group to complete their video presentation. If you have already finished filming, use this time to edit your video in iMovie and add some cool effects." For the rest of the day, students were primarily focused on finalizing and enhancing their presentations.

Case 3: Ms. Mindy's Implementation of Integrated STEM

Ms. Mindy's overall implementation followed the flow of the written curriculum (See Table 4.3), leveraging the client, Arcade Inc., to contextualize the learning process. Ms. Mindy's instructional strategy spanned twelve days. Following the curriculum, the client communicated with the students each lesson through a client letter or memo to maintain the storyline and contextualization of the learning through the EDC.

Lesson 1

This lesson was conducted in a single day. Ms. Mindy began by dedicating a significant portion of class time to an electricity quiz (a pre-test related to the larger grant project). Following the quiz, she introduced the client letter (See Table 4.4) and explained, "We are going to read it out loud. As I read, please highlight anything you find important or any words that might be difficult for the average reader." After reading the first letter, she informed the students that they would receive daily memos from different engineering teams at Arcade Inc., detailing their tasks for each day. Upon finishing the letter, she encouraged students to underline any unfamiliar words. To prompt participation, Ms. Mindy then asked if anyone knew what an electromagnet was, guiding them to use context clues within the text to understand its meaning.

Ms. Mindy often incorporated literacy strategies into this lesson, particularly during the reading of the client's letter. She asked students to underline words for comprehension. This worked both to ensure that students understood the content of the memos and as another opportunity for students to practice reading strategies. She instructed students to identify and categorize nouns and verbs and unfamiliar terms related to the subject matter. Encouraging active engagement, she prompted them to circle and note down words they found challenging, using the same method she employed. For instance, students needed to grasp the meaning of the word "rigged" to comprehend the context of the design challenge fully. This approach aimed to enhance both reading comprehension and vocabulary acquisition among the students, as well as understanding the context and needs of the client.

Ms. Mindy urged students to rely on context clues, saying, "Let's use our context clues to figure out what is correct. However, it has just been revealed, much to our dismay, that claw games are rigged." She also guided students to discern the emotions conveyed by the company president.

T: What kind of emotion are we getting from Mr. Nova?

T: Happy or sad. How does he feel about this? Angry, kind of? Why do you think he is angry?

S1: Some people think that they might not win, and then no one can play there now.

T: So they're kind of getting angry and upset. If nobody wants to play, how would he feel about that? Sad?

S2: Sad.

T: What's the whole point? Why does he want?

S3: Money. You get money.

T: But we know that the claw game is rigged, and it is not a good thing. He goes on to say that whether or not this is true of our games does not matter if people don't want to play.

S1: So, is it fair?

T: Yes, it's rigged, which means it's not fair.

Furthermore, she stressed the importance of the company's need for a new arm.

T: Why do they want you to make that new arm?

T: Why aren't they playing the game right now?

S2: It's rigged.

T: Remember that new word he learned? It's rigged. Okay.

She then directed students to open their iPads and navigate to the article (see Appendix) on rigged games. As students began reading, she provided clarification, "The claw machines allow the owner to select a desired level of profit, and we just measure that when there is only one. This isn't isolated to one partnership." Following this, she engaged students in a brief exercise:

T: I'm going to pass around this piece of scrap paper. Please take your pen and write down one piece of evidence that proves the claw machine is rigged. You have about 15 seconds to jot it down.

This activity encouraged active reading and critical thinking as students identified evidence supporting the assertion that claw machines were rigged.

Lesson 2

This lesson lasted one day (Day 2). Ms. Mindy commenced the class by revisiting the concept of "rigged," making connections with what they learned in the previous lesson. Following this, she introduced a miniature claw game toy, acknowledging that some students might not have prior experience with such games by saying, “Some of you may not have played a claw game before. Since this whole project is about games, I thought it might be helpful for you to be able to play claw games.” Ms. Mindy emphasized the relevance of the claw game to their ongoing project centered around games, aiming to provide students with a hands-on understanding of claw game mechanics.

As the lesson progressed, Ms. Mindy introduced a new client memo in a unique way, telling the students that they had received an email from the company. She began by asking, “Who’s it from?” to which the students replied, “Orion.” Ms. Mindy then elaborated on Orion’s message:

> Your teacher informed me of your problem-solving abilities, so I would like to present you with a template. This template will allow you to demonstrate your capability to use electricity to light a bulb. By completing the template, I will be able to verify not only your problem-solving skills but also your evidence to support your solution.

She clarified that the memo came from Orion Nova at Arcade Inc. For the remainder of the class, students explored the concept of electricity flow. Ms. Mindy guided them to visualize the path of electricity, encouraging them to identify its starting point and direction using arrows.

Lesson 3

During this single-day lesson (Day 3), the focus was on learning about electromagnets. Ms. Mindy began by stating, “What you’re going to do today is more than just looking at it. You will actually be using this—our electromagnet. This is important because it's what we need to develop for Arcade Inc." She then directed the students' attention to the engineering design process and asked, "Where are we in our engineering design process? Why? Because we're still learning about electromagnets. Today, we're going to explore what an electromagnet is." Although Ms. Mindy briefly connected the activity to its larger context, most of the class time was spent on understanding how electromagnets work.

Lesson 4

On Day 4, the lesson focused on conducting a controlled experiment to learn about the impact of different variables on the strength of an electromagnet. Ms. Mindy began by introducing a new client letter, explaining that the client was impressed by the students' work from the previous week (see Appendix). She shared that the client was eager to continue collaborating and had assigned the students their first controlled experiment. The task involved testing the impact of the number of coils on their electromagnets, a variable that the client considered the most valuable for their research.

Ms. Mindy emphasized the importance of this experiment, explaining that their findings would contribute directly to the client's research. She then instructed the students to collect data during their experiment and to summarize their findings in two to three sentences to report back to the client. As she continued to read the client letter, Ms. Mindy highlighted a crucial detail: "It says you must collect the data and report back. Ladies and gentlemen, when scientists report their data, it must be comprehensible to others." She used this opportunity to contextualize the significance of clear data reporting, stressing that scientific data must be accessible and understandable even to those without a science background. This emphasis helped students recognize the broader impact of their work beyond the classroom.

For the remainder of the class, students focused on testing the coils of their electromagnets. As they worked, Ms. Mindy reiterated the importance of data collection. She prompted them by asking, “What does Orion want us to collect data on? Specifically, the number of coils.” She further guided them on how to organize their findings: “Just like a graph, every data table needs a title for the coils. Understand?” This clear instruction underscored the importance of proper data labeling and presentation, preparing students to convey their results effectively to the client.

Lesson 5

This lesson spanned two days, Day 5 and Day 6. On Day 5, no contextual integration was observed. However, Day 6 started with Ms. Mindy re-engaging the students with the project context. She began by asking them to recall who the client was, setting the stage for introducing a new client letter. The client’s message read:

> We reviewed your report based on what you presented from Day Three. We need each group to complete another controlled experiment. To collect sufficient data about the electromagnets, please pick another variable to test from the list below and report back to us with your findings. Please include your data table and graph in your report.

After reading the letter, Ms. Mindy elaborated on what the client was asking them to do. She reminded the students, “The variables you listed last time include the material the wire is wrapped around, the thickness or gauge of the wire, the number of batteries, the size of the battery, and the number of alligator clips. We have already tested the coils."

Building on the previous experiment, she continued, "When we tested the coils, we created our data table and formulated our claim. We examined two variables: the independent variable, which was the number of coils, and the dependent variable, which was the number of washers. For today's experiment, you need to make sure your claim addresses the variable you are testing and its impact on the number of washers."

This explanation connected the new experiment with the previous work the students had done, reinforcing the process of identifying and clearly documenting the independent and dependent variables in their data collection. Through this discussion, Ms. Mindy guided students to ensure that their experiment and data presentation were aligned with the client's requirements but her approach was implicit as she didn't make it clear how science was connected to the EDC or client.

As the lesson continued, Ms. Mindy directed the students' attention to their engineering design process, prompting them with questions: "Do we know what our problem is? What's the issue with Arcade Inc.? What are Orion's expectations of us? Overall, what did Orion request us to create?" After a moment of reflection, students responded that the task was to design an electromagnetic arm. Ms. Mindy briefly informed the students, "Your next step is to utilize this data to develop your prototype."

Lesson 6

Over the course of two days (Days 7 and 8), the students concentrated on planning and constructing their prototypes. Ms. Mindy kicked off Day 7 by asking the students to present the data they had collected from their experiments to the rest of the class. After each group shared their findings, she facilitated a discussion to help them connect their results to the project's overarching goals.

Ms. Mindy then guided the conversation with a series of questions, starting with, "Do we understand the problem we're trying to solve? What exactly is the issue here?" She prompted the students to think critically about the problem they were addressing, reminding them, "The claw in the game seems unfair, right? So, what does Orion expect from us? They want us to design something that ensures the claw functions properly."

She followed up by checking the students' understanding of the electromagnetism, making sure they were prepared to move forward with their designs. Next, Ms. Mindy directed the discussion toward the planning phase, asking:

> What's the plan for creating the solution? Remember, your design needs to address the problem. Are you developing a solution to fix the issue with the claw? Have you outlined a blueprint for the electromagnetic arm? Have you finalized your plan yet?

The students indicated were still in the learning phase but about to start to the planning stage. Ms. Mindy acknowledged their progress and encouraged them to focus on translating their understanding of electromagnets into a concrete design.

On Day 7, she then shared a new client memo, stating:

> Fantastic work. We're nearing our deadline, and each team will need to devise a design plan and construct a prototype by the end of the next workday. Additionally, you'll be required to furnish a detailed depiction of your design, accompanied by justifications for each decision made.

She clarified that the client was pleased with their progress and tasked the students with providing a design along with its justification.

Ms. Mindy presented the client letter (see Appendix), specifying that the client requires a labeled diagram detailing the design of their electromagnetic arm. She clarified, “Include everything that will be integrated into your electromagnetic arm: the coil, wire gauge, bolt material, battery, and battery holder.” Ms. Mindy emphasized that they were tasked solely with creating the arm prototype and were not responsible for its vertical movement, which falls under the mechanical engineer’s jurisdiction. She reiterated, “We are electrical engineers, focused solely on crafting the arm that will perform the picking-up function.”

Ms. Mindy revisited the initial client letter (See Table 4.4), prompting the students, “What is a constraint? Go back to the client letters. These are the very first letters Orion [client] sent to us.” She directed their attention to the constraint checker worksheet and instructed, “I want you to read this and search for the specific rules Orion [client] wants, especially regarding creating the strongest electromagnet known to man, okay?” Ms. Mindy then asked the students to inform her when they had finished reviewing the constraint checker worksheet so they could proceed with planning.

After working in a groups. She gathered students and she delved into the business dynamics of the claw machine, engaging in dialogue with the students to illustrate her point after the constraint checker worksheet:

T: Imagine if every time you put in 25 cents, you won. You’d keep playing, right?

S1: But then I’d lose money.

T: Nobody wants to lose money, okay? However, consider this scenario: someone puts in 25 cents, but the electromagnet is super weak, and they don't win. Did I make money or lose money?

S2: Made money.

T: Right. And that's good for business. Then, another person tries and doesn't win either. Again, I make money. Now, if nobody wins, nobody's happy. And if you're not happy, will you come back to play again?

S3: No.

T: So, I need you to keep playing in order for me to make money.

T: I'm still going to lose money. So, you have to figure it out as a group. Do you want everybody to win? Do you want everybody to lose? Do you want it to be 50/50? 75/25? 60/40? What are we talking about here?

T: Think about what Orion wants because he is our client. Okay, but he also needs to make sure that he makes money from the end user—you, as the people that play the game—or the end user that he can get money back.

On Day 8, Ms. Mindy began the lesson by setting a clear deadline for the students. She stated, "Today is your deadline. Within the next 30 minutes, you need to have your electromagnet fully constructed and tested. When you test it, make sure to record your data on the back of your paper. Are you testing it just once? No, you should test it multiple times. I recommend at least three tests, after which you'll find the average."

The focus of the class was on completing the electromagnet and gathering data through testing. During the session, Ms. Mindy made a brief contextual connection to the client project. She asked, "If the client wanted a super strong electromagnet, but it ends up being too strong or too weak, then I won't make any money. So, what do we want to do?" This question prompted students to consider the practical implications of their designs and the importance of balancing strength in the electromagnet.

Aside from this moment of contextual integration, the rest of the class time was primarily dedicated to the technical aspects of building and testing the electromagnets, with limited further discussion on how their work directly connected to the client's needs.

Lesson 7

Over the span of four days (Days 9, 10, 11, and 12), students focused on redesign. On Day 9, Ms. Mindy revisited the EDP and the client needs, initiating a discussion with the students:

> T: Let's take a look at our engineering design process and see where we are. So, do we know our problem?
>
> S1: Yes.
>
> T: What is it? What's the problem?
>
> S2: The claw game is rigged.
>
> T: So what does Orion want you to do?
>
> S3: Make a new one.
>
> T: Did you learn about electromagnets?
>
> S4: Yes.
>
> T: Did you plan to solve this problem? Did you plan it?
>
> S5: Yes.
>
> T: Did you try it and test it?

S6: Yes. We did.

Ms. Mindy reinforced for the students that previously they constructed the electromagnet and tested it by picking up the washers, and that now they must decide whether to proceed with redesigning or deem it satisfactory. She emphasized that during this class, students have to determine if their creation meets the required criteria and constraints. Ms. Mindy assured the students that it was acceptable to decide that the current design was adequate while also acknowledging that some may choose to opt for redesigning, which is equally acceptable.

On Day 10, there was a lack of contextual integration in Ms. Mindy's class. The majority of the session was dedicated to exploring various facets of magnetism, encompassing discussions on different types of magnets, their strengths, and their interactions with other materials.

On Day 11, Ms. Mindy commenced the lesson by informing the students that the client was awaiting their reports, and the toy design team had decided that each team should select the material most suitable for their toy. Emphasizing budget constraints, she stated, "You have a total budget of $40 for the entire design, and each team will receive a prize to attach and test with your electromagnet." She urged teams to make any necessary adjustments to meet all constraints and criteria.

Furthermore, she instructed, "Once your team has finalized your design, produce a video presentation adhering to the guidelines outlined in the rubric." Ms. Mindy clarified that the next workday would be dedicated to finalizing designs and commencing video presentations. These videos would be forwarded to the client, with the company president set to review them.

Ms. Mindy stressed to the students that their focus should be squarely on the final design and that there’s no need to reinvent anything. She articulated, “You’re not going to reinvent the wheel here. You already did that. You’ve already done all the work.” Reinforcing the importance of budget management, she reiterated, “I have $40 for you to spend, and to assist you in staying within budget, I’ve prepared a cost sheet detailing the expenses.” She reminded them that the budget must not be exceeded. Addressing a student’s query about going under budget, she clarified that while students could spend less than the allocated $40, they were not permitted to surpass the budget.

On Day 14, the primary objective was to finalize the video presentation for the client. Ms. Mindy reiterated to the students that according to the memo, they needed to complete both the electromagnet and the video. Emphasizing the importance of providing comprehensive details to the client, she asked, “What else should we include in persuasive writing? How about pictures? Why would we include pictures?” Additionally, Ms. Mindy prompted students to ensure they mentioned the constraints within the video presentation.

Ms. Mindy also emphasized the significance of body language and facial expressions for the video presentation, highlighting their ability to aid clients in recalling important details. She specifically instructed students to incorporate certain key points into the presentation, stating, “These are the things you must include: constraint number one, whether the electromagnet picked up the toy intermittently, the description of the electromagnet including details such as the number of coils, gauge of the wire, number and size of batteries, and the number of alligator clips. All of these specifics must be included." For the remainder of the class, students diligently worked on their video presentations.

Cross-Case Analysis

While the three teachers' overall approach to the unit was similar, nuanced differences emerged in how they emphasized contextual integration within their lessons. The cross-case analysis revealed four emerging themes: science connections with the EDC, literacy connections, maintaining the EDC storyline, and making connections to the work of STEM professionals. These themes are explored in greater detail below.

Science Connections with EDC

The integrated STEM unit encompassed four science lessons where students explored the properties and applications of electromagnets (Lessons 2, 3, 4, and 6; see Table 4.3). Instead of treating these lessons as isolated science activities, the teachers aimed to connect the scientific content with the EDC. However, there were notable differences in how Ms. Ashley, Ms. Mindy, and Ms. Helen approached this integration, with Ms. Ashley and Ms. Mindy standing out in their efforts to contextualize the science lessons within the broader EDC context.

All three teachers introduced each lesson by framing it around understanding the problem, providing relevant background information, and highlighting the needs of the client. This approach used the EDC context as a driving force for exploring the science content, grounding the student's learning in a practical, real-world scenario. However, the level of integration between the science content and the EDC varied among the teachers.

While all three teachers introduced new client letters that linked the science activities to the specific client problem, Ms. Ashley and Ms. Mindy made strong, explicit connections between learning about electromagnets and the client’s needs. Throughout the lessons, they frequently referenced the client’s requirements, consistently reminding students that their experiments were aimed at meeting real-world needs rather than merely conducting scientific inquiries for their own sake. Additionally, Ms. Ashley and Ms. Mindy consistently highlighted the importance of communicating the experimental findings back to the client, reinforcing the notion that engineering projects often involve solving user-centered problems. By stressing that the client was eager to learn the results, they underscored the significance of not just conducting experiments but also effectively communicating outcomes. This ongoing communication with the client framed the experiments, giving students a clear sense of purpose and relevance in their work. As such the science lessons were contextualized rather than isolated classroom activities.

In contrast, Ms. Helen’s approach to framing the lessons within the EDC was less explicit. While she referred to the client as “the boss,” her efforts to integrate the science experiments within this context were limited. She occasionally reminded students of the importance of completing their experiments for their boss but did not fully articulate how the data they were collecting would benefit the client. Similarly, while she encouraged students to present their findings, her focus was mainly on using presentations as a tool for peer learning and reflection within the classroom. She did not extend this activity to include how students might communicate their results to an external audience, such as the client. As a result, the connection between the science activities and their real-world applications remained implicit.

While all three teachers attempted to integrate science content with the EDC, Ms. Ashley and Ms. Mindy demonstrated a more thorough and explicit connection between the lessons and the client’s needs. Their approach emphasized the importance of framing experiments within a real-world context, maintaining ongoing communication with the client, and grounding the students’ work in meaningful, client-focused problem-solving. In contrast, Ms. Helen’s integration of the EDC was more limited and implicit, focusing on internal classroom learning rather than extending the application of science and engineering to address client-driven problems.

Literacy Connections

All three teachers incorporated literacy into the lesson by guiding their students through a client letter, a central part of the design challenge. During this activity, they prompted students to underline or circle key information, thereby reinforcing important concepts like the client’s role and introducing relevant vocabulary, including terms like “prototype” and “rigged.” The term “rigged,” however, required more in-depth exploration for the students to understand why they needed to create a new electromagnetic arm despite the presence of an existing one. While each teacher used literacy approaches, they differed in the depth and strategies used to unpack these concepts, particularly the meaning of “rigged.”

The discussion of “rigged” was pivotal across the lessons, as it clarified the problem’s context and provided students with a deeper understanding of the client’s needs. All three teachers took the opportunity to explain “rigged” and its implications, emphasizing that the existing claw game was designed unfairly to prevent players from winning. While Ms. Ashley explained the unfairness of the current claw game and why a new design was necessary, Ms. Mindy and Ms. Helen went a step further in their approach. They modeled a real claw game using a mini-game demonstration to give students a concrete example of what “rigged” meant. By incorporating real-world examples, Ms. Mindy and Ms. Helen provided a more tangible understanding of the concept. This strategy allowed students to see firsthand how the game’s design made it difficult for players to succeed, highlighting the significance of creating a new electromagnetic arm.

Maintaining the EDC Storyline

Ms. Ashley, Ms. Helen, and Ms. Mindy effectively maintained the EDC storyline by incorporating client letters throughout the curriculum. These client communications were introduced in each lesson, outlining the client’s needs and the next steps for the students to take. By embedding these letters into the unit, the teachers created a storyline that closely mirrored real-world scenarios, where clients demand specific solutions to problems. From the beginning, all three teachers engaged students with the client letters, ensuring the storyline was well-established. In the first lesson, they took time to clarify who the client was, what the students were expected to do, and why they were doing it. By framing the problem, they guided students to define the client’s identity, explore the client’s specific requirements, and understand the issue that needed solving. This approach emphasized the real-world relevance of the unit, making the learning experience more engaging and meaningful. Additionally, each teacher underscored the importance of communication, with the client letters serving as an ongoing means for the client to convey their evolving needs. These letters were intricately woven into the lessons, providing a consistent context that drove the students’ work.

However, the teachers differed in how consistently they maintained this storyline throughout the unit. Ms. Ashley successfully integrated the client context into nearly every lesson, with the exception of Day 5, where the connection between the client and the learning objectives was not explicitly reinforced. Similarly, Ms. Mindy maintained the storyline for most of the unit but did not make the connection with the client clear on Days 5 and 10. Ms. Helen, on the other hand, struggled more with maintaining the storyline consistently. While she initially incorporated the client context into her lessons, there was a noticeable lack of integration on Days 5, 6, 9, and 12. During these days, the connection to the client was missing, and the learning activities lacked the real-world relevance that the client storyline provided.

Ms. Helen and Ms. Mindy adopted a unique approach compared to Ms. Ashley by incorporating a miniature claw game toy into their lessons. This hands-on experience allowed students to interact with a real claw game, thereby deepening their understanding of the unit's storyline. By engaging directly with the toy, students encountered the excitement and frustration commonly associated with playing such games. This interactive element created a tangible connection between the lesson's scientific concepts and the students' real-life experiences, enhancing the relevance and engagement of the unit.

Building on this experience, Ms. Mindy took the lesson a step further by exploring the business dynamics of claw machines, enriching the storyline and providing a real-world context. She led an in-depth discussion by presenting a hypothetical scenario where every 25-cent play resulted in a win, prompting students to think critically about the implications of this setup. Through dialogue, Ms. Mindy emphasized the importance of balancing winning outcomes to ensure business profitability. She explained that while occasional wins could attract players, allowing continuous wins could lead to financial losses for the business, as it would diminish the challenge and excitement that draw players to such games. She encouraged students to consider the client's objectives, highlighting the need to find a balance between player satisfaction and profitability. This approach not only maintained the storyline but also helped students grasp the complexity of real-world problem-solving within the context of engineering design.

Despite the differences in their teaching methods, all three teachers effectively utilized the client letters to frame the unit's overarching problem. This narrative approach helped students with a clear understanding of who the client was and what they needed, anchoring the learning activities in a real-world context. While Ms. Mindy and Ms. Helen added unique, interactive elements to deepen the students' engagement, Ms. Ashley consistently reinforced the client's perspective throughout the unit, guiding students to consider both technical and communication aspects in their final presentations.

Making Connections with the Work of STEM Professionals

All three teachers made efforts to connect the unit's activities to the work of STEM professionals, though the depth of these connections varied. Ms. Mindy and Ms. Helen briefly mentioned the relevance of STEM careers during their lessons but did not explore this topic in detail. They provided a surface-level context, giving students a general idea of how STEM careers might relate to the concepts they were learning but stopping short of a deeper exploration.

In contrast, Ms. Ashley took a more comprehensive approach to contextualize the roles of STEM professionals for her students. She consistently connected the classroom activities to the daily responsibilities and practices of scientists and engineers, helping students see how their learning aligned with real-world STEM work. One of her key strategies was introducing the concept of professional norms. Ms. Ashley compared the students' collaborative efforts in the classroom to the teamwork exhibited by engineers, emphasizing values such as respect, punctuality, and curiosity. This helped students understand that working in STEM involves more than just technical skills; it also requires effective communication, cooperation, and a mindset geared toward continuous learning.

Additionally, Ms. Ashley stressed the importance of maintaining notebooks, drawing a direct parallel to how engineers and scientists document their daily activities. She explained that professionals in these fields use notebooks to keep detailed records of their experiments, designs, and observations, which are crucial for tracking progress, reflecting on their work, and communicating findings to others. By encouraging her students to adopt this habit, Ms. Ashley demonstrated the practical applications of documenting their work, showing that this was not just a classroom exercise but a skill they might use in future STEM careers.

Through these explicit connections, Ms. Ashley offered her students a glimpse into the world of STEM professions, illustrating how the skills and practices they were developing could be relevant to their future paths. This approach not only contextualized the students' learning but also provided them with insights into the habits and behaviors of STEM professionals, making the idea of pursuing a career in these fields more tangible and attainable.

Discussion

The push to incorporate engineering into pre-college science education is primarily based on the belief that engineering can enhance students' understanding of scientific concepts (e.g., Apedoe et al., 2008; Capobianco et al., 2018; Schnittka & Bell, 2011). Engineering design tasks are seen as valuable opportunities for students to apply and develop scientific ideas in meaningful contexts (Atman et al., 2007; Johri & Olds, 2011; Puntambekar & Kolodner, 2005; Roth, 2001). Despite these potential benefits, research has highlighted numerous challenges teachers face when attempting to implement the EDC in their classrooms (Berland et al., 2014; Capobianco & Rupp, 2014; Crotty et al., 2017; Silk et al., 2009; Walkington et al., 2014). In the present study, we explored three teachers' contextual integration manifested in their implementation during the integrated STEM unit. The findings demonstrate that each teacher employed diverse strategies to connect science content, literacy, and real-world problem-solving within the EDC. Despite variations in their approaches, all three teachers maintained a consistent narrative that emphasized the purpose and relevance of the design challenge.

A key element observed across all classrooms was the effort to make explicit connections between science and EDC. Research has shown that integrating engineering with science concepts in meaningful contexts is essential to support students' learning (Pleasants et al., 2021). In this study, each teacher incorporated elements such as a client letter, ongoing communication, and iterative design processes to reinforce the EDC's real-world focus. For example, the teachers regularly referred to the needs of a client throughout the unit, reminding students that their experiments were not merely academic exercises but part of a larger effort to solve a tangible problem. By framing experiments within a client-centered context, the teachers fostered a sense of purpose that likely motivated students to engage more deeply with the engineering problems (Cunningham & Lachapelle, 2014; Ganesh & Schnittka, 2014).

Furthermore, the teachers' use of client letters and updates provided students with a storyline that contextualized their learning experiences. By maintaining this ongoing narrative, the teachers encouraged students to view the design process as a continuous cycle of problem-solving and refinement, a key characteristic of engineering (NRC, 2012). This iterative process was made more meaningful by embedding it within the client's needs, emphasizing that engineering design is not linear but involves ongoing adjustments based on feedback and results (Crismond, 2001; Cunningham & Hester, 2007). This strategy not only reinforced the iterative nature of engineering but also helped students see the relevance of their work beyond the classroom.

The teachers also worked to connect the EDC to real-world STEM professions, though the depth of these connections varied. Some provided surface-level context, briefly mentioning the relevance of STEM careers without delving deeply into the specifics of how the classroom activities aligned with the daily responsibilities of scientists and engineers. In contrast, others integrated more detailed discussions about the practices of engineers, helping students understand how their problem-solving and inquiry skills relate to the work of STEM professionals (Lachapelle & Cunningham, 2014; Sheppard et al., 2009). This variation suggests that while teachers recognize the importance of contextualizing STEM careers within their lessons, additional support may be needed to facilitate more comprehensive integration.

Despite these differences, all teachers succeeded in incorporating multiple disciplines into the EDC. They blended science, literacy, and engineering elements to create a cohesive learning experience. For example, during the unit, students explored electromagnetism through hands-on experiments while simultaneously engaging in literacy activities, such as reading and analyzing client letters. Some teachers spent more time with students to read and analyze the client. These interdisciplinary connections are crucial, as engineering requires the application of scientific and mathematical knowledge to solve real-world problems (Cunningham & Lachapelle, 2014; Sheppard et al., 2009).

The findings also point to the importance of curriculum design in supporting teachers' efforts to integrate engineering and science. Although all three teachers utilized a common curriculum that encouraged cross-disciplinary connections, they each adapted the material to suit their instructional style and the needs of their students. This adaptability reflects the diverse methods teachers can use to support science and engineering integration, a challenge often faced by elementary educators (Capobianco & Rupp, 2014; Wendell et al., 2014). By leveraging different strategies, such as framing the problem with client letters or modeling real-world examples like claw games, the teachers were able to contextualize the EDC and maintain the storyline to engage students.

The study highlights the potential of the engineering design challenge as a framework for integrating science, literacy, and real-world problem-solving in the elementary classroom. While each teacher adopted a diverse approach to contextual integration, common elements such as ongoing communication with the client, emphasis on iterative design, and connections to STEM professions provided a foundation for learning. These strategies demonstrated the value of engineering as a conduit for interdisciplinary learning. Future research should further explore how professional development and curriculum design can support teachers in making more explicit connections between science and engineering, thereby maximizing the benefits of an integrated STEM approach.

Limitations

A key limitation of our study is that it is based on the practices of only three teachers, making it difficult to generalize our findings about what effective contextual integration in STEM education should look like. Each teacher's approach to incorporating context was similar, reflecting individual teaching styles and classroom dynamics. As a result, we cannot draw broad conclusions about the best practices for contextual integration in STEM education. Furthermore, our study does not measure the impact of these implementations on students' learning outcomes in science. Without directly assessing student understanding and knowledge gains, we are unable to determine whether the strategies used by these teachers were successful in enhancing students' comprehension of science and engineering concepts. Therefore, while our study provides insights into different methods of integrating context into the integrated STEM unit, it does not offer definitive evidence of their effectiveness in advancing student learning.

Conclusion

The study highlights the potential of the engineering design challenge as a framework for integrating science, literacy, and real-world problem-solving in the elementary classroom. While each teacher adopted a diverse approach to contextual integration, common elements such as ongoing communication with the client, emphasis on iterative design, and connections to STEM professions provided a foundation for learning. The study highlights practical strategies employed by teachers, such as maintaining the EDC storyline, facilitating ongoing communication with the client, and emphasizing data presentation.

These strategies provide actionable methods for other educators seeking to implement the EDC in their classrooms. By focusing on these pedagogical approaches, teachers can create a more engaging and meaningful context for students, thus reinforcing the connections between engineering, science, and mathematics. These strategies demonstrated the value of engineering as a conduit for interdisciplinary learning. Future research should further explore how professional development and curriculum design can support teachers in making more explicit connections between science and engineering, thereby maximizing the benefits of an integrated STEM approach.

Furthermore, this study adds to existing research on the critical role of engineering in STEM education, especially at the elementary level. It reinforces the importance of incorporating engineering principles into the classroom as a means to connect scientific and mathematical concepts in real-world contexts. The strategies observed in this study not only contribute to enhancing teacher practices but also highlight the potential for engineering design to serve as a framework for integrated STEM learning.

Our work underscores several aspects of teacher practice that could benefit significantly from additional support and education. By providing teachers with comprehensive training on integrating the EDC into science instruction and offering robust curriculum resources, we can better position them to enhance student learning in both science and engineering. This level of support is essential if we are to realize the full potential of incorporating engineering into elementary science education. Through this multiple case study, significant implications for integrated STEM education have emerged.

Implications

This study reveals several key implications for stakeholders involved in STEM education, particularly curriculum developers, teacher educators, district administrators, and professional development facilitators. One notable finding is the importance of explicitly linking classroom activities, science concepts, and engineering practices to enhance student learning. While all teachers in the study made efforts to connect engineering activities to real-world contexts, some of these connections remained implicit, potentially limiting students' ability to fully grasp how their work addresses authentic problems. As suggested by Pleasants et al. (2021), explicit connections between science concepts and the EDC are crucial for deepening students' understanding. This underscores the need for professional development that emphasizes strategies for making these linkages more explicit during classroom instruction.

For curriculum developers, the detailed analysis of how teachers implemented integrated STEM units provides valuable insights into how written curricula are translated into classroom practices. Understanding the variations in implementation across different classrooms can inform the development of future curricula that are more adaptable, providing guidance on how to effectively embed real-world contexts into STEM learning. Additionally, by examining the nuances in teachers' integration practices, curriculum developers can design resources that support a more consistent and explicit alignment between science content, engineering practices, and the overarching goals of the EDCs.

For teacher educators and those designing professional development programs, the study offers actionable guidance for supporting teachers in integrating STEM disciplines. The cross-case analysis highlights the need for professional development initiatives to focus on strategies that help teachers make explicit the connections between classroom experiments, data collection, and real-world problem-solving. By equipping educators with the skills to clearly articulate these connections, professional development can better prepare teachers to implement integrated STEM learning experiences that are relevant and meaningful for students.

Furthermore, the findings point to a need for additional research into the relationship between integration practices and student outcomes in STEM education. Future investigations should examine how different approaches to integrating STEM concepts, particularly the use of EDCs, affect student learning and motivation. This line of research can provide deeper insights into the pedagogical content knowledge required for teachers to successfully implement integrated STEM strategies, thereby informing both teacher preparation programs and professional development initiatives.

Chapter 5: Conclusion

Overarching Findings

This dissertation encompasses three interconnected studies investigating integrated STEM (I-STEM) education at both the curricular and classroom implementation levels. The first study analyzed thirty-four STEM activities published by the National Science Teacher Association (NSTA) to assess how well they reflect the core characteristics of I-STEM (Roehrig et al., 2021). This mixed-method study combined quantitative assessments with qualitative evaluation to examine the presence and quality of the core characteristics, such as real-world contexts, engineering design challenges (EDC), interdisciplinary content integration, development of twenty-first-century skills, STEM practices, learner-centered approaches, and promotion of STEM career awareness. While the activities demonstrated alignment with many essential I-STEM characteristics, the ways in which these characteristics were incorporated into curricular resources, and their quality, varied.

The second study examined how an elementary science teacher implemented I-STEM practices in her classroom, with a focus on integrating context and content. Context integration was accomplished by embedding the client throughout the lesson, reinforcing the real-world relevance of the student's work and enhancing their engagement with the EDC. The teacher also facilitated content integration by establishing both explicit and implicit connections across science, engineering, and other STEM disciplines, enabling students to see how these fields intersect to solve complex problems.

Building on the insights from the second study, the third study conducted a multiple case analysis to examine how three elementary teachers implemented the same

I-STEM curriculum. Despite working with the same materials, each teacher's instructional approach varied based on contextual factors such as their teaching experience, classroom environment, and the needs of their students. All three teachers emphasized iterative design processes, engaged students in client-driven tasks, and connected lessons to STEM professions, fostering interdisciplinary learning through engineering challenges.

Together, these studies provide valuable insights into how I-STEM are represented at both the curricular and implementation levels. They highlight the potential of engineering design challenges as a unifying framework for integrating science, literacy, and problem-solving in elementary education. The findings suggest that while curriculum design plays a crucial role in promoting I-STEM education, teachers' ability to adapt content to their unique classroom contexts is equally essential. By embedding real-world problems, fostering interdisciplinary connections, and facilitating iterative learning, educators can create meaningful learning experiences designed to prepare students for future STEM opportunities.

Implications for Education

The findings from this dissertation provide valuable insights and practical implications for advancing integrated STEM (I-STEM) education at both the curricular and classroom levels. These insights are particularly relevant for educators, curriculum developers, policymakers, and professional development facilitators, all of whom play a critical role in enhancing the quality and effectiveness of STEM education.

A significant outcome of this research is the creation and implementation of the Integrated STEM (I-STEM) rubric—a powerful and versatile tool designed to evaluate

STEM curricula. This rubric is more than a resource for classroom teachers; it serves as a comprehensive framework for professional development, curriculum design, and research. By providing a structured approach to assess lesson plans, it ensures that they align with key I-STEM principles such as interdisciplinary learning and real-world problem-solving.

However, the concept of "real-world" in STEM education requires careful scrutiny. While "real" can mean anything in theory, it often means *nothing* to students if it lacks direct connection to their lived experiences. The value of real-world problems lies in their relevance to the communities where students live and learn. For students, problems must resonate personally and reflect challenges they understand and care about. Without this connection, lessons risk becoming abstract exercises, disengaged from students' realities.

Analysis of thirty-four NSTA activities using the I-STEM rubric revealed significant inconsistencies in how well these activities incorporated core I-STEM characteristics. This underscores the urgent need for intentional curriculum design that prioritizes meaningful connections between STEM disciplines and students' communities. When curricula are deeply tied to the environments, cultures, and challenges students encounter daily, STEM learning becomes transformative. It fosters not only interdisciplinary understanding but also a sense of responsibility and engagement.

For curriculum developers, the rubric is a tool to elevate lesson materials, ensuring they are engaging, rigorous, and socially relevant. By emphasizing direct ties to students' communities, educators can design STEM experiences that are not just technically sound but also deeply impactful. These experiences empower students to see themselves as problem-solvers, equipped to address challenges that matter to them and their communities. Real-world problems are no longer just theoretical—they are actionable, inspiring students to connect their learning to the real-life issues that shape their world.

The findings also emphasize the pivotal role teachers play in bringing I-STEM curricula to life in the classroom. Even when using the same instructional materials, teachers' interpretations and adaptations varied based on their experiences, student needs, and classroom contexts. This variability underscores the importance of professional development programs that extend beyond content delivery, equipping teachers with strategies to adapt and contextualize STEM activities effectively. These programs should focus on helping teachers implement iterative design processes and incorporate real-world scenarios and client-centered tasks, ensuring students understand the relevance of STEM in practical contexts.

Furthermore, professional development initiatives must prioritize fostering interdisciplinary teaching practices. Teachers need support in making explicit connections across STEM disciplines, facilitating inquiry-based learning, and creating collaborative learning environments. Encouraging teachers to reflect on their practices and share challenges with peers helps cultivate a community of practice, enhancing the overall quality of STEM education.

To successfully implement I-STEM, it is essential to empower educators with comprehensive strategies for STEM integration. Policymakers, administrators, and professional development facilitators must work together to help teachers develop a sophisticated understanding of I-STEM practices. Without such knowledge and strategies, the broader STEM integration movement may fall short in achieving meaningful improvements in student outcomes.

Future Work

The findings of this dissertation underscore the importance of quality curriculum design, teacher implementation, and professional development in promoting integrated STEM (I-STEM) education. However, further research is needed to build on these insights, addressing key areas that remain unexplored. Future studies should focus on deepening our understanding of how I-STEM practices impact student learning outcomes, refining tools for curriculum evaluation, expanding teacher development initiatives, and promoting equitable access to STEM education.

A logical next step is to explore how both I-STEM curricular characteristics and I-STEM teaching practices influence student engagement, achievement, and conceptual understanding in STEM fields. While this dissertation examined how curriculum and teacher practices align with I-STEM, future research should assess the effectiveness of these practices in promoting specific learning outcomes. Longitudinal studies that track students' progress over time could provide valuable insights into how integrated STEM experiences impact their cognitive development, interest in STEM fields, and preparedness for future STEM careers. Understanding these outcomes would also help policymakers and educators refine instructional strategies to maximize the effectiveness of I-STEM education.

The integrated STEM rubric developed in this dissertation holds promise as a tool for evaluating curricula and guiding instructional design. However, future research is needed to further validate and refine the rubric by applying it across diverse educational settings, including different grade levels, regions, and subject areas. Studies should explore how the rubric performs in practice, identifying areas for improvement and assessing its impact on curriculum development and lesson planning. Researchers could also investigate how the rubric influences teachers' instructional practices and whether its consistent use leads to improved student outcomes.

Given the variability in how teachers implement STEM curricula, additional research should focus on effective strategies for supporting teachers through professional development. Future studies could investigate how professional learning communities promote collaboration, reflection, and the exchange of best practices among educators. Research should also explore how teachers adapt I-STEM curricula to meet the needs of their students and classroom contexts, examining the challenges they face and the strategies they employ to overcome them. Insights from this research can inform the design of professional development programs that emphasize both STEM content knowledge and the pedagogical skills needed to foster interdisciplinary learning.

Equity remains a critical issue in STEM education, particularly in engaging underrepresented groups and ensuring inclusive learning environments. Future research should investigate how I-STEM curricula and practices can be tailored to meet the needs of diverse learners, including students from marginalized communities, girls, and students with disabilities. Studies that explore culturally responsive teaching strategies within the I-STEM framework can provide valuable guidance for educators seeking to create more inclusive learning experiences.

Measuring interdisciplinary learning remains a challenge in STEM education. Future research should focus on developing metrics that capture the extent to which students engage with multiple STEM disciplines and apply their knowledge across contexts. Such metrics would provide valuable tools for assessing the effectiveness of I-STEM activities and informing instructional design. Studies could explore how students develop interdisciplinary thinking through hands-on projects, engineering design challenges, and client-based tasks, offering insights into how these experiences contribute to their overall STEM literacy.

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Appendix

Lessons	Client Memo
Lesson 1	“My company, Arcade Inc., has a problem. We design and build arcade games, and one of the longest and best games is the claw game Diggin’ for Fools’ Gold. For some reason, people are losing interest in the game and aren’t playing it as much. I’ve attached a news article about claw games, which explains a little about why. We need to figure out how to get people interested in our game again. Can you help us?” “As you saw from my previous letter, Arcade Inc. we at are in a terrible situation. Our claw game, ‘Diggin’ for Fools’ Gold,’ travels around to various carnivals, parties, stores, and restaurants. However, as that news article says, some claw games are rigged! Players can’t win! Whether or not this is true of our games does not matter. People do not want to play our claw game since they don’t think they will win.” “You came up with some great ideas for how to get people to play our game again. We thought about it too, and we have decided that we need a new ‘claw’ so customers will think our game is new and different. We would like to contract you to develop a prototype of an electromagnetic arm that will be used in the game instead of the claw. We will only be replacing the claw in our machines, as the other components are still in working order. We have a team of mechanical engineers that will scale up the prototype you develop and place it in our games.” We need you to develop the electromagnetic arm and also explain to our mechanical engineers how to make the electromagnet. You will need to justify your reasoning because the mechanical engineers are responsible for scaling up your design and need to make sure they get all the pieces in the correct place. It is also important that you remember that we want this game to be fair, but also a game of skill, where customers will win some of the time, but not every time. You will receive daily memos from our various engineering teams that are working on this project. The memos will instruct you on your daily tasks.” “Thank you for your excellent questions. I have prepared answers to most of the questions, and I will attach them to this letter. I have also given your teacher some more information, so you can ask your teacher additional questions as they come up.

Lessons	Client Memo
	As you start to learn about designing electromagnets and begin work on designing our new claw arm, if you have any more questions for me or my team, just give them to your teacher who will pass them along to us.”
Lesson 2	“Our toy design team has been working on designing the toys that will be found inside the new version of the claw game. They realized that most toys won’t work with the electromagnets that you are designing. They plan to attach some material that is attracted to magnets to each toy so that the electromagnetic claw will work. They need your teams to help determine which material will work best with a magnetic arm. We have provided each team with a bag of materials. Test to see which ones are attracted to a magnet and provide a report on which material should be used for the final toy design.”
Lesson 3	“Thanks for the great recommendations yesterday. Our toy design teams will use the materials you recommended to make the “tags” for the toys in the Diggin’ for Fools’ Gold game. Great work! Today we will need you to begin to investigate electromagnets. You’ll need to know how they work before you can begin your designs. We’d also like to know what variables in an electromagnetic can be changed to change the way it works. We’ve sent along a simple electromagnet for you to use in order to complete this task.”
Lesson 4	“Your teacher shared with us the list of variables you came up with yesterday, and we were impressed by your work. We would like you to continue by testing how the number of coils affects the strength of the electromagnet. You should design a controlled experiment to conduct this test. We think that of all the variables you have listed, testing the number of coils could be the most valuable data for your research. We will need you to collect data and report back your findings in 2-3 sentences.”
Lesson 5	“We reviewed the results of your experiment on the number of coils, and based on what you presented from your experiments, we need each team to complete another controlled experiment in order to learn more about electromagnets. Please select another variable to test from the list below and report back what you learn. Please include a data table and graph in your report. The variables you listed last time that we would like you to investigate are: 1. the material the wire is wrapped around 2. the thickness (gauge) of the wire 3. the number of batteries 4. the size (voltage) of the battery

Lessons	**Client Memo**
	5. the number of alligator clips 6. the length of core material 7. the thickness of core material”
Lesson 6	“Wow! Fantastic work. We are getting very close to our deadline. We will need each team to come up with a design plan and build a prototype of your electromagnet arm by the end of the next work day. Along with a detailed picture of your design, you need to provide a justification for each decision you make. Please remember to adhere to the following criteria and constraints from our previous communications: Criteria: • The prototype should be an electromagnet that can be attached to an arm, not a claw. • You must justify your design decisions using data. • You must be able to explain your design. Constraints: • End users should win some of the time, but not every time. • You may only use the materials provided. • You only have one class period to plan your prototype design and one class period to create your prototype. We have also included a sample toy with a metal “tag” attached for you to use in testing your design.”
Lesson 7	“Thank you for your hard work on your initial designs. We were very impressed with what you came up with, but we’d like a slightly more realistic test. This time, we’ve sent along a whole set of toys. You’ll notice that there are three sizes of toys—small, medium, and large. For your test, you should try to pick up different-sized toys and keep track of which toys you were able to pick up and which toys fell. Before you test, please redesign your electromagnetic arms and make any changes necessary to meet all constraints and criteria. We’d like to see the toys picked up and moved 4-6 times out of 10 tries. We’d also like players to win small toys more often than larger toys. If your redesigned prototype does not meet that criteria, you must redesign it again and update your justification. Once your team has your final design, prepare a poster that explains your design, why you made it the way you did, and how successful you think it is. Your teacher has specific details for you on how we want you to make your posters. Please get this to us by the end of your next workday.”

Claw Machines are Rigged Article

Claw machines are rigged—here's why it's so hard to grab that stuffed animal.

At some point or another, you've probably played one of these claw machines, hoping to score the plush toy of your dreams. But despite your skill at perfectly positioning the claw over the prize and activating it, you've found that the pincers just don't grab tightly enough to pick up a stuffed animal.

It's not your imagination. Those claw machines are rigged. But they're rigged in a surprisingly clever way—and not the way most people suspect. The claw is programmed to grab tightly only part of the time.

Some people think the claw machine is so hard to win because the stuffed animals are packed so tightly together. But the bigger reason is more insidious than that: the claw machine is programmed to have a strong grip only part of the time.

This isn't a closely kept secret. It's publicly available information, pulled straight from the instruction guides for the biggest claw games out there. Open the manual for Black Tie Toys' Advanced Crane Machine.

The machine's owner can fine-tune the strength of the claw beforehand so that it only has a strong grip a fraction of the time that people play. The owner can manually adjust the "dropping skill," as well. That means that on a given number of tries, the claw will drop a prize that it's grabbed before it delivers it to you. The machines also allow the owner to select a desired level of profit and then automatically adjust the claw strength to make sure that players are only winning a limited number of times.

This isn't isolated to one claw machine or one company—this is standard practice industry-wide.

Want to win a prize from the Bling King? The machine's instruction manual shows you'll likely have to play dozens of times. The owner can program beforehand how often the claw's grip is strong or weak.

The big decision for machine owners is how fair or unfair they want to make the game. They could adjust the machine so that the claw only operates on full power one out of every 23 times. That would, in theory, create a profit of around 50 percent. (The machine also has ways to ensure this—if a player wins with a "weak claw," the machine can wait even longer before sending full power to the claw.)

But owners also have to be careful, since no one wants to play a machine that never seems to work. So, they might want to accept less profit in the short term by allowing the claw to be stronger more often, thereby giving the machine a better reputation.

For the player, however, there’s no way to know in advance how strong or weak a machine is.