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Exploring Effective Practices of an Elementary STEM Block Program

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Abstract: Creating a STEM-driven culture incorporating engineering habits of mind and 21st century skills at an early age could impact students' STEM interests and knowledge. Therefore, early exposure to effective engineering design practices could create a foundation for a STEM program. This exploratory case study examined the integration of a STEM program in an elementary-level school. Survey, interview, focus group, and observational data were analyzed and coded to determine effective practices of the STEM program. This paper focuses on the emergent themes of the (a) critical role of the specialist, (b) instructional design, and (c) integration of the engineering laboratory. The STEM specialist at Gemini Elementary School provided the teachers with the foundation for the in-depth acquisition of STEM content and pedagogical skills. Teachers were provided with team planning time that focused on the instructional design of the STEM Block lessons. Through collaborative settings, teachers and the specialist were able to design modern real-world problems for students that allowed students to apply engineering design practices to find solutions. The results of this study point to the need to increase the number of STEM programs embrace engineering design in elementary schools.

Keywords: *STEM program, STEM education, engineering design process, elementary schools, case study*

Introduction

The United States (U.S.) is the land of opportunity that developed some of the world's greatest scientific and technological innovations (National Science Foundation, 2016). However, its future world standing may depend on its populace being prepared to think from a scientific and technical perspective; and, most importantly, people's economic opportunities may be limited to those with science, technology, engineering, and mathematics (science, technology, engineering, mathematics; STEM) backgrounds (Langdon et al., 2011; Sargent, 2017). A STEM-literate workforce and citizenry enhance the U.S. capability to compete globally and sustain efficient, diverse industries and production necessary to meet 21st century demands (NSTA, 2021). Exposing all students to STEM education at an early age may enhance their interest in STEM careers and provide an equal opportunity to all students (DeJarnette, 2012). The importance of providing students with early exposure was brought to light by the early learning framework presented by the *Partnership for 21st Century Skills* (P21, 2017) and other researchers (Bybee & Fuchs, 2006). Incorporating engineering opportunities into STEM schools could be one tool educators use to capture students' interest and engagement while introducing them to real-world applications and STEM careers. According to Tanenbaum (2016), early interest in STEM concepts is the foundation for creating a competitive STEM workforce prepared to meet the challenges of the rapid development of scientific and technological innovations. However, there is little research regarding implementing integrated STEM initiatives in elementary schools (Peters-Burton et al., 2019). In addition, there is a dearth of research regarding STEM schools; thus, a need for STEM school case studies needs to be conducted (Lesseig et al., 2019). This case study sought to identify features of an integrated STEM program and how the use of an engineering laboratory supports integrating the STEM curriculum in a STEM elementary school in Texas. The following research question was explored in this study: What features of an elementary-level integrated STEM program have the potential to contribute to its effectiveness?

STEM's Impact on a Global Economy

A strong STEM foundation will help secure the United States' position as a world leader in innovation and contribute to the economic opportunities available to all citizens. More recent BLS projections include all STEM jobs to reach over 10 million occupations by 2030, which is a 10.0% increase from 2019 (BLS, 2020). Quality jobs could be critical to keeping the U.S. globally competitive because of the purchasing power they provide its citizens to fuel the national and global economies. A dynamic global economy and workforce have prompted an increase in the discussion concerning STEM education and concern over a shortage of prepared STEM workers and educators worldwide (Kennedy & Odell, 2014; Sargent, 2017). To remain competitive in a global economy, key stakeholders have encouraged students to develop an interest in STEM (Cunningham et al., 2015; National Science Board, 2007; President's Council of Advisors on Science and Technology, 2012). People's standard of living may also be connected to STEM innovations and their impact on the U.S. economy (Shernoff et al., 2017).

Additionally, maintaining the U.S.'s ability to compete globally comes from having STEM-literate citizens and a workforce that also includes technical workers that "help secure our health and safety, revitalize our utility infrastructures, monitor our food production, and improve our manufacturing efficiencies and capabilities" (NSTA, 2021, para. 5). However, the lack of students' STEM preparedness threatens the U.S.' economic growth (Rozek et al., 2017) and may threaten students' future opportunities for work. Building a solid understanding of the importance of an engaging and practical STEM application may involve capturing students' interest earlier to help develop them for a competitive and innovative global market.

Our rapidly changing world has demanded that students be flexible and respond quickly to the innovations, advancements STEM careers require, and new jobs that have not been created (Morgan et al., 2013). Businesses have been compelled to adapt quickly and require a workforce trained in critical thinking and problem-solving skills to meet complex 21st century challenges (Miller, 2017). Early interest in STEM concepts is foundational for creating a competitive workforce (Tanenbaum, 2016). Therefore, efforts to incorporate real-world problem solving and critical thinking in U.S. educational systems, especially with elementary students, may equip students with 21st century skills, thinking, and competencies.

Obstacles to STEM Education

However, obstacles exist to implementing STEM education. Inconsistencies in integrating STEM into K-12 educational systems create problems in comparing what pedagogical approaches best support learning and how results compare among disciplines (NRC, 2014). These inconsistencies add to the difficulty of making connections among STEM subjects and courses, so students may fail to understand how the integration of these subjects applies to real-world applications (Breiner et al., 2012). The difficulty in defining STEM and STEM integration could limit the implementation of STEM education in more schools and limit the students entering the STEM workforce in the future (NRC, 2014; Schneider et al., 2016). Educators, policymakers, and other stakeholders must agree on common terminology to increase the effectiveness of STEM education.

Since there are various definitions of STEM and multiple interpretations of STEM integration (Roehrig et al., 2021), it is difficult for stakeholders to agree on exactly how to increase the opportunities for STEM education in the U.S. (Schneider et al., 2016). Some researchers define integrated STEM 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" (Kelley & Knowles, 2016, p. 3). In comparison, others state that it is "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" (Moore et al., 2014, p. 38). The lack of agreement on the definition makes it difficult for educators to implement comprehensive and uniform STEM curricula.

In addition, elementary school educators may be reluctant to implement STEM curricula due to their lack of STEM content knowledge (Hammack & Ivey, 2017; Watson et al., 2020). In a study by Hammack and Ivey (2019), participants appeared adamant that they would not implement engineering concepts from training due to a lack of background knowledge. Moreover, many elementary teachers teach multiple content areas and may not have adequate planning time to implement STEM content that is not assessed in standardized testing elementary (Hammack & Ivey, 2019). Therefore, some elementary teachers may perceive incorporating engineering, a necessary STEM concept, as not feasible due to administrators' focus on "state-mandated assessments and reading" (Hammack & Ivey, 2019, p. 516). Alleviating issues and concerns facing gatekeepers, such as elementary teachers, may encourage openness to new pedagogical approaches.

Benefits of Integrating STEM

Multiple interpretations have led to the evolution of STEM education and its role in society, expanding interpretations and benefits of integrating STEM concepts throughout schools. The National Science Teachers Association (NSTA) is taking a more expansive understanding of STEM education. It includes fields such as computer science, "the designed world," and robotics that integrate science, technology, engineering, and mathematics concepts to solve real-world problems by creating modern solutions (NSTA, 2021). STEM integration helps determine how things work and how technologies are created and provide students with authentic learning experiences, including problem-solving, innovation, and design, which are three themes with high priorities on every nation's agenda (Hernandez et al., 2014). Advocates of integrated STEM education argue that it is essential to teach STEM across disciplines in an integrated approach so that students and teachers develop an awareness of how to make connections between real-world problems and improve learning (NRC., 2014; Subramanian & Clark, 2016). An interdisciplinary integration requires focusing on a real-world problem and using 21st century skills (i.e., critical thinking, problem-solving, and content knowledge) to solve a problem (Wang et al., 2011). This approach is crucial because it helps students build the skills needed to understand our ever-changing world and obtain skills needed for the STEM workforce (Smith et al., 2015).

Students' interest in STEM increases as their curiosity, exploration, and understanding of how integrated STEM concepts are connected and impact the world around them (English, 2016). DeJarnette (2012) suggested the need to expose students to STEM education at an early age. An integrated STEM approach in schools may be one way for students to learn about global real-world issues and create interdisciplinary solutions that address complex problems (English, 2016; NRC, 2014; Sanders, 2008; Tsupros et al., 2009). Additionally, Sanders and Wells (2005) posit that intentionally integrated concepts and practices of SteM and applications of technical/engineering design-based learning can result in a trick-down effect where other content areas integrate STEM into instruction.

One of the most incredible benefits of providing an integrated STEM curriculum to students is acquiring 21st century skills (P21, 2015) and engineering habits of mind (Loveland & Dunn, 2014). The National Science Teaching Association (NSTA), in conjunction with the Partnership for 21st Century Learning (P21) and National Research Council (NRC), includes "life and career skills; adaptability; complex communication/social skills; nonroutine problem solving; self-management/self-development; and systems thinking" as part of 21st century skills (NSTA, 2011, p. 2). Complex communication and social skills include effective collaboration with peers that builds STEM knowledge, promotes discourse with different viewpoints, and comes to a consensus when working together (Loveland & Dunn, 2014). Systems thinking, an underrepresented skill within classrooms (Salado et al., 2019), allows students to make connections across STEM disciplines and is a natural way to apply engineering habits of mind (Lippard et al., 2019). Six engineering habits of mind (i.e., systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations) encompass many 21st century skills (Loveland & Dunn, 2014; National Academy of Engineering & National Research Council, 2020). Thus, including these skills and habits of mind fosters students' STEM knowledge and understanding across disciplines (English, 2021).

Integrating Engineering in STEM

With increasing STEM education awareness, educators understand the importance of hands-on activities and their role in providing the necessary foundation for STEM learning and achievement (Margot & Kettler, 2019). Many schools are beginning to stress the integration of all areas of STEM using the engineering design process (EDP). The EDP is the practice of "testing the most promising solutions and modifying what is proposed based on the test results leads to greater refinement and ultimately an optimal solution" (NRC, 2012, p. 210). In some instances, critical concepts of the EDP are applied in math and science courses. According to English (2019), this will provide students with foundational problem-solving skills in engineering design that are transferable and applicable across STEM disciplines and fields. According to Capraro et al. (2013), there are many engineering design models schools can adopt and follow. The K-12 engineering framework expects educators to focus on design and problem solving while incorporating STEM concepts (Strimel, 2012). Applying STEM processes and practices such as the EDP by educators and students helps create a STEM mindset for students (Peters-Burton et al., 2019). In addition, educators should “promote engineering habits of mind” (Berland, 2013, p. 22) because they incorporate several 21st century skills (P21, 2015). Similarly, the K-12 science education standards incorporate STEM (mainly science) into engineering design challenges. Engineering allows students to visualize and apply complex concepts relevant to them and our society (Morgan et al., 2013). An interdisciplinary approach and brainstorming of possible solutions allow students to increase their creativity and ingenuity as engineers do in the real world (Gormley & Boland, 2017; Marcos-Jorquera et al., 2016). Furthermore, modeling a “think tank” environment to “learn and adapt to innovate solutions to new problems” provides students with the opportunity to demonstrate their ability to work together like engineering teams (Larson et al., 2017, p. 2). Incorporating a STEM-driven mindset can provide a shared vision and expectation for learning that promotes a STEM-driven school culture (Waters & Orange, 2022). This culture includes engineering habits and applications that could be essential to instill in students at an early age.

According to Berland (2013), incorporating engineering into science is a great idea, but teachers' pedagogical methods and classroom philosophy may not be conducive to integrating the EDP. Classrooms working on the EDP should apply their multidisciplinary approach to learning through solving problems with a focus on engineering objectives rather than simple math and science knowledge and skills (Margot & Kettler, 2019). Additionally, engineering education can be used in science classrooms to accentuate engineering habits of the mind that are important in the engineering process and applicable across STEM fields (Lippard et al., 2019; Schnittka, 2012), and most science classrooms only focus on science curricula. A significant difference to note is that scientific inquiry focuses on gathering empirical data which supports a hypothesis and explains why something is occurring. In contrast, the EDP has students create a project or solve a problem using constraints and specifications (Nadelson et al., 2011). Teachers who incorporated the EDP into their professional practice and classroom experiences often included their students in their successes and failures as they worked through classroom experiences with them. "This visible failure, she [the teacher] made clear, served as evidence–for themselves and the students–of their ongoing pursuit of new ideas and continuous improvement" (Peters-Burton et al., 2019, p. 454). Wendell et al. (2017) support the importance of learning from failure in the classroom but believe it needs to be intentionally scaffolded into students' EDP experiences so they understand the critical role reflections play in the EDP.

The International Technology and Engineering Educators Association (ITEEA) created the Engineering by Design (EBD) program to integrate science, technology, and mathematics into the engineering design process to better prepare today’s students for future advancements in technology and engineering (Strimel, 2012). During the EDP, students can collaborate while increasing their critical thinking, creativity, and communication skills while solving real-world problems. The EDP emphasizes that all activities (i.e., researching, calculations, budgeting, creating, and testing) should be contextualized around the design challenge (Strimel, 2012). For example, many engineers must work under specific constraints, such as budget constraints, limiting the design by eliminating different possibilities (Dym et al., 2009). Constraints, however, are usually limited to understanding budgets, time, and materials, rather than real-world problems associated with social and political challenges (Roehrig et al., 2021).

Additionally, EDP challenges should include real-world connections. Maiorca and Mohr-Schroeder (2020) discovered that design challenges such as the Marshmallow Challenge may engage students in EDP but lack an authentic learning experience. According to Kapur and Bielaczyc (2012), teachers who promote this culture also challenge students to be in a state of productive struggle where they "are challenged yet not frustrated and remain sufficiently engaged in problem-solving" (p. 50). Productive failure is a critical element of the EDP. English (2021) echoes this need but emphasizes the importance "to increase awareness of, and capitalise [sic] on, children's skills as independent problem-solvers, who relish challenges, preserver in the face of failure, and learn from both what "works" and what does not" (p. 117). The goal is to engross students in such a significant way that they learn the engineering design process while creating authentic learning experiences that increase their critical thinking, STEM knowledge, and ability to connect to real-world innovations (Maiorca & Mohr-Schroeder, 2020). Therefore, engineering is an excellent way to integrate STEM concepts (NASEM, 2020).

Methods

This exploratory case study (Creswell, 2007; Lichtman, 2010) examined the integration of a STEM program in an elementary-level school. Gemini Elementary STEM School (GES) is a pseudonym for a suburban elementary school in Texas. The researcher selected it as the site for this study because it implemented a STEM program known as the STEM Block that included an engineering laboratory. A case study was an appropriate qualitative framework to employ because selecting one program within the school to study allowed the researcher an in-depth exploration of how GES integrated STEM with attention to the site context and educators' perceptions that framed the program (Lichtman, 2010). The study addressed the following research question: What features of an elementary-level integrated STEM program have the potential to contribute to its effectiveness?

Participants

Forty-four GES K-5 STEM educators were asked to participate in this study based on their role as a school leader or teacher and their knowledge of integrating the STEM curriculum into students' STEM Block experiences. Participants volunteered in the study's K-5 STEM Educators' Perception Survey (n=17), focus groups (n=16), and interviews (n=4) and did not object to the use of a pseudonym to protect participants' anonymity. All GES educators were invited to participate in the focus group sessions. Due to time constraints and school commitments, 16 chose to participate. Table 1 presents the demographics of the focus group and interview participants. The teachers, STEM content specialist, and librarian are female, and the principal is male. This data allowed the researcher to cross-reference the survey data with the focus group and interview data to identify participants who attended the focus groups and interviews and completed the survey.

Table 1

Focus Group and Interview Participant Demographics

Role or Grade Level	*Pseudonym*	*Years Experience in Education*	*Ethnicity*	*Age Range*
Principal	Mr. Petit	26+	White	55+
STEM Specialist	Dr. DuBois	21-25	White	45-54
Librarian	Ms. Jemison	16-20	African American	45-54
Kindergarten	Ms. Fernandez	6-10	Hispanic	25-34
	Ms. Bell	26+	White	45-54
	Ms. King	6-10	Hispanic	25-34
	Ms. Lopez	6-10	White	25-34
1st Grade	Ms. Anderson	11-15	African American	45-54
	Ms. Bowe	26+	White	55+
2nd Grade	Ms. Lander	11-15	Multiracial	25-34
	Ms. Spitz	6-10	White	35-44
	Ms. Lovett	11-15	White	35-44
3rd Grade	Ms. Shepard	6-10	White	35-44
4th Grade	Ms. Kennedy	21-25	White	45-54
5th Grade	Ms. Hudson	11-15	White	35-44
	Ms. Neil	26+	White	55+
	Ms. Cooper	21-25	White	45-54

Data Collection

Survey

The researcher created the K-5 Educators' Perception Survey to gather preliminary data regarding educators' perceptions of STEM education and the components of a successful STEM school. The anonymous online survey consisted of a cover letter containing implied consent by participants taking the survey, 15 open-ended items, four dichotomous items (three yes/no items and one gender), and ten nominal items, which included demographic questions and took an average of 14 minutes to complete. At the principal's request, the survey was emailed to the STEM content specialist at the site, where she forwarded the email containing the cover letter and link to the survey to 44 staff members. For this paper, the survey items the researcher focused on were how teachers perceive how planning with team members impacts STEM Block lessons, using the EDP in the engineering laboratory, and effective practices of a STEM school.

Focus Groups

After reviewing the survey data, the researcher wrote the semi-structured focus group questions to provide a more thorough description of STEM integration and components of a successful STEM school. The researcher emailed the STEM specialist a copy of the focus group questions to share, and participants received a paper copy during the session. There were seven focus groups with 16 participants. Focus groups were offered throughout the day at 30-minute intervals. This allowed the teachers to attend during their conference or lunch periods. The principal and specialist encouraged teachers to attend during their conference period.

Interviews

The researcher conducted semi-structured interviews lasting 20-40 minutes each. The researcher interviewed the principal on the phone and a STEM specialist and librarian on site. A copy of the interview questions was emailed before the interview and focused on educators' perceptions of the elements of a successful STEM school. After the initial focus group and observational data were collected, a follow-up interview was conducted with a second-and third-grade teacher to provide a deeper insight into the engineering laboratory.

Observations

The STEM specialist offered the researcher to observe the students' EDP experience. The researcher thought this would be a great way to observe and compare the program to the previous data collected. Therefore, the researcher agreed to observe the fourth-grade EDP STEM Block on Cargo Boats for four consecutive days. The observations lasted approximately 60-90 minutes in duration. The researcher took notes in her field journal and pictures in the engineering laboratory to document how students work through the Cargo Boats EDP during their STEM Block week. In addition, the researcher set up two flip video cameras on the first two days of the observations so she could check her notes in her field journal.

Data Analysis

Before importing data into QSR International's NVivo10 qualitative data analysis software, the researcher examined the data to explore possible trends between the transcribed and observational data. Queries were run to detect high-frequency words (e.g., STEM, engineering, science, students, technology, curriculum, teachers, technology, and math), which provided a synopsis of the overall data. Since a more in-depth analysis was necessary to understand participants' perceptions fully, text search queries were run to look for potential relationships between topics involving the integration of STEM content. The researcher ran variations of the text queries (i.e., integrate, integrating, and integration) to examine different aspects of the same concepts. Figure 1 shows results from text queries referring to participants' different responses.

Additionally, the researcher coded the data according to the most common words (i.e., professional development, planning, time, engineering lab, key components, culture) and then used NVivo to auto-code that data. Common codes comprised professional development, exploratory phase, team planning, makerspace, communication, time, collaboration, STEM education approach, critical thinking, creativity, problem-solving, engineering, future improvement, real-world experiences, connections, and integration. They were a part of the comprehensive study. The coded data regarding the engineering laboratory was compared to the researcher's field notes and observational data. Common trends in the data were looked for when coding was complete. The trends were explored to see where the codes overlapped and could be combined into themes. The analyses resulted in the themes presented in the following section.

Findings

Based on the survey, interview, focus group, and observational data, seven common themes emerged from the more extensive study of K-5 STEM educators' perceptions of STEM education: instructional leadership team, professional development, teacher collaboration, making connections, vision and culture, 21st century skills, and integration of the engineering laboratory. Based on the intertwined themes, we collapsed these initial themes into three major themes: (a) critical role of the specialist, (b) instructional design, and (b) integration of the engineering laboratory for this paper.

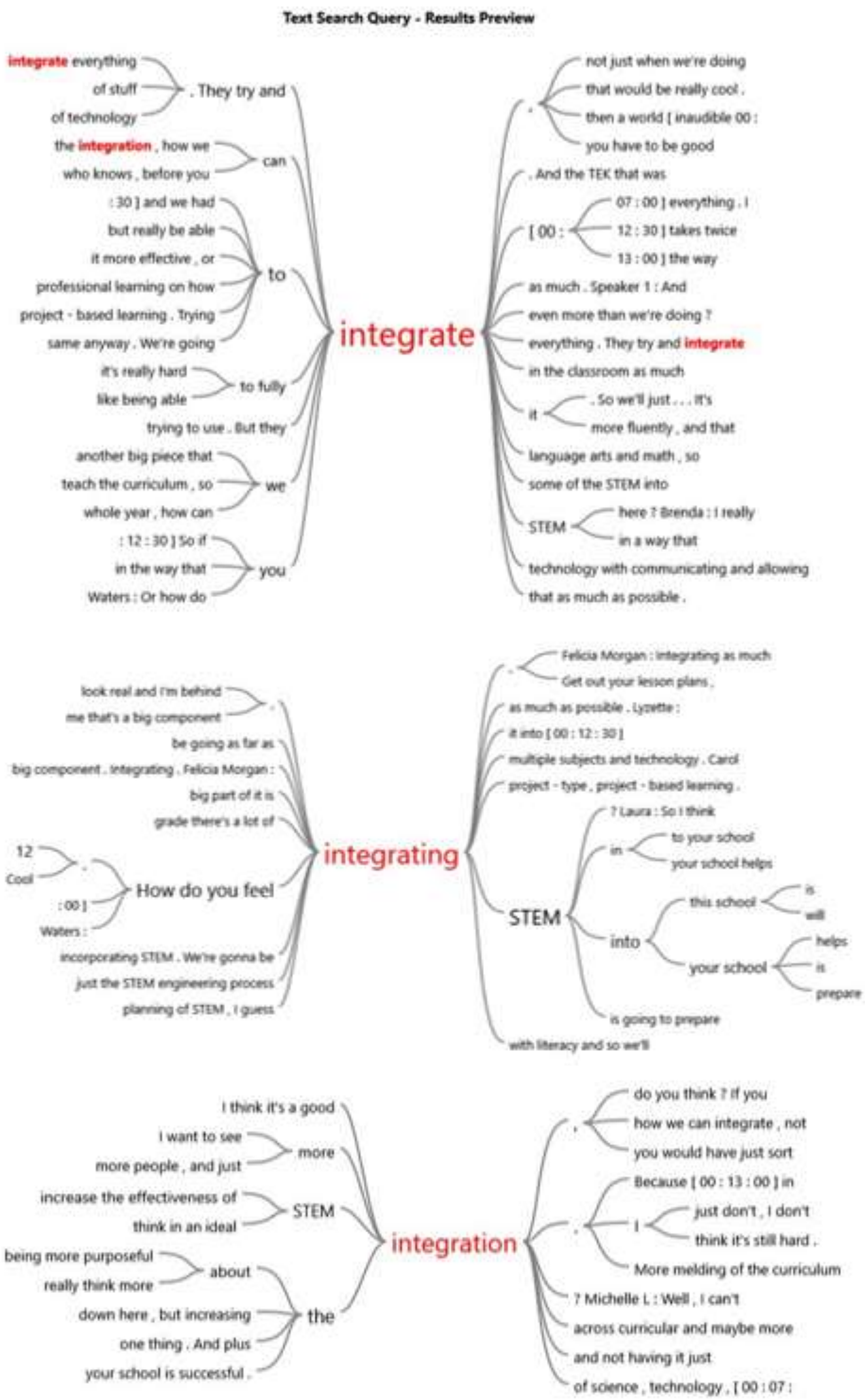
Critical Role of the Specialist

According to participants, the primary integrative curriculum at GES occurs during the "STEM Block," an engineering laboratory for all grade levels. Qualitative data underscored that the support provided by the GES STEM specialist fostered a robust instructional design foundation for teachers. During year one of implementation, the specialist created and designed the STEM Block engineering design lessons used across all grade levels. Additionally, she facilitated the EDP experiences for students and modeled best teaching practices for teachers in the engineering laboratory. In subsequent years, the STEM specialist encouraged teachers to co-teach the EDP classes. As a result, teachers were more comfortable and willing to learn EDP lessons, integrate STEM into daily instruction, and begin leading the EDP classes in the third and fourth years of implementation.

The vision of GES focuses on preparing, inspiring, and creating lifelong learners who can use critical thinking skills to address future global challenges. The "STEM Block" at GES is the primary integrative curriculum, according to the survey, focus group, and interview data, which is an engineering laboratory for all grade levels… indicated support provided by the GES STEM specialist provided the instructional design foundation for teachers to feel more comfortable integrating STEM and learning the EDP lessons. Exploration of K-5 STEM educators' perceptions of critical components that made GES a successful STEM school revealed that team planning is essential to creating an effective EDP instructional design for the STEM Block lessons. One first-grade teacher felt the STEM specialist's role was vital to the success of their school. She believed the specialist supported her and was helpful when she stated:

Figure 1

Text Query Results



> Our wonderful science coach and the other coaches work together, encouraging us, and providing opportunities to learn more STEM activities, giving us the tools, we need to implement activities in our classroom, and helping us in any way they can.

The specialist developed the initial EDP lessons and continually trained teachers during implementation. In addition to the training at the beginning of the school year, teachers participate in half-day planning sessions once every nine weeks, where they work with the specialist to implement the engineering design lesson. The principal recalled:

> Our STEM coordinator [specialist] spent a lot of time in the lab, the STEM lab [engineering laboratory] with our teachers, making sure they understand how to go through the lessons. And so that was a key component, I think, is really helping out those teachers that are more uncomfortable with it or not used to it and taking them through it. So that was probably the biggest parts.

The principal perceived that the STEM specialist was a key component of successful instructional design and implementation of STEM curricula in their school. In addition, it was a constant reminder of the goals that encouraged teachers to achieve confidence and build their STEM content knowledge and skills by integrating the EDP.

Most of the teachers attribute their initial successes with STEM integration to the implementation of the EDP provided by the STEM specialist. Based on teachers' comments, the specialist trained the teachers on how to facilitate the engineering laboratory lessons and incorporate the EDP into the school's identity and culture. "She's pushing the kids to go beyond the boundaries, especially during that design part," the second-grade teacher shared. She also noted that the teachers in the engineering laboratory are watching and learning as the specialist models how to question the students to get them to develop their ideas at a higher level.

During the initial phases of STEM education implementation, the specialist trained teachers on the engineering lessons and instructed students in the engineering laboratory during the summer and start of school prior to implementation. During the implementation year, one second-grade teacher, now a third-grade teacher, recalled how the specialist took the burden of designing EDP lessons off the teachers. She recalled what many teachers believed:

> [The STEM specialist] was the one kind of in charge. There was discussion about it [designing plant packages EDP] with the second Grade [teachers] but for the most part since we were at [year] zero, we had input but it was more about we need to follow our curriculum because that's how we're gonna get our grades, that’s how we’re gonna get our learning, our [standards] met.

The specialist taught the lessons to the students and modeled the facilitation of the lessons for the teachers. It appeared to the researcher that the teachers appreciated the help from the specialist to help them understand the engineering process and integrate STEM into their classrooms. Furthermore, the teachers initially depended on the specialist to learn how to implement the integration of the STEM Block EDP lessons.

The specialist's role has transitioned from being the primary facilitator of the EDP for the students to taking a step back and allowing the teachers to facilitate the engineering laboratory. For example, a second-grade teacher said the specialist is in the laboratory two to three times a week. She also stated how teachers are encouraged to begin developing and modifying lessons for the EDP. She recalled:

> Now that we've been through the process so many years, she kind of puts it on us and just kind of is more of a guide for us, and we'll run things past her, like when I started doing the PowerPoints, I'd run it past her.

Since this is the fourth year of implementation, teachers are taking a more significant role in the engineering laboratory. According to the second-grade teacher, the specialist will now guide teachers and ask them how they can modify their ideas to "make it even more of a challenge." "There's still modeling going on, but a lot of us have been through the process so many times, it just kind of becomes natural after you go in there so much," the second-grade teacher concluded. The principal has set aside professional development opportunities at the beginning and throughout the school year. In addition to a teachers' planning period, he provided a half-day of planning each nine-week grading period to allow teachers to collaborate on the EDP during the engineering week.

Instructional Design

STEM Block lessons were initially developed by the STEM specialist and teachers with numerous years of experience. Teachers' collaboration and methodical planning during the instructional design of the engineering lessons were identified as an essential component of the STEM Block and engineering laboratory. As teachers acquire STEM content, pedagogical knowledge, and skills, they can collaborate effectively, improve the instructional designs of current EDP lessons, and create new ones. The STEM Block lessons (Table 2) for K-5 grade levels were developed to cover a 3-5-day engineering unit using the engineering design process. According to the original program proposal, the purpose of these lessons is to incorporate the EPD into a STEM block every nine weeks for K-5 students. The proposal also stated that language arts, mathematics, and social studies would be integrated into each grade level's different units of study when applicable.

As part of the implementation of the engineering laboratory, teachers attended schoolwide professional development that taught them how to integrate STEM. The principal also allocated specific planning time before the beginning of the 2014-2015 school year, where teachers focused on learning and reviewing the EDP lessons. The specialist attended these planning sessions to discuss and model the lessons. The teachers attend STEM-specific professional development opportunities and training each subsequent year to help them integrate STEM education.

Table 2

STEM Block Examples for K-5

Grade Level	STEM Block Examples
Kindergarten	Make your own Observer
	Sailboat Races
	Engineering Pollinators
First Grade	Invention Boxes
	Ramps and Sleds
	Designing Windmills
	Egg Drop
Second Grade	Huff and Puff House
	Robotics Kits and Moon Lander
	Designing Plant Packages
Third Grade	Loco Bean Harvester
	Roller Coasters
	A Slick Solution: Cleaning an Oil Spill
Fourth Grade	Cargo Boats
	Oobleck Lander
	Marble Mover
	Mars Rove
Fifth Grade	Design a Water Filter
	Designing Alarm Circuits
	Solar Cars

Teachers began contributing more to the lessons' instructional design as they gained STEM content knowledge. According to most of the teachers and the specialist interviewed, the principal set aside half-day planning every nine weeks for teachers to plan and review the engineering lesson. According to the interviewees, planning focused on the engineering lessons and was in addition to team planning and PLCs. A second-grade teacher shared that these meetings involved teachers in the same grade level meeting to identify the state standards for that nine-week timeframe. During this time, teachers collaborated to find a critical concept that could be applied to solve a real-world problem and draw arrows connecting the cross-curricular concepts, not just STEM. According to the specialist and second-grade teacher, teachers select a topic within the area with the most connections, usually within science. Then, they begin the daily planning the STEM Block unit (Figure 2).

Previous themes are supported when teachers obtain new knowledge and ideas from conferences—they share the information with colleagues and begin collaborating on ways to adapt it for their curriculum. For example, a second-grade teacher recalled how one of her colleagues attended a conference and won a lab about Fulton's ferry. She remembered her colleague saying, "Well, this would fit with what we're doing right now," and recalled that her team decided, "Well, let's develop this into a STEM lesson." Therefore, they modified the lesson to meet the needs of their STEM students and made connections to the TEKS and standards during their cross-curricular team planning. As a result, increasing teachers' confidence and STEM pedagogical knowledge led to improving the EDP instructional designs.

Figure 2

Example of Daily Planning for the Third-grade STEM Block

Monday	Tuesday	Wednesday	Thursday	Friday
Language Arts: Read Aloud Lucas and His Loco Bean Predict what it is Science: Give loco beans to students Explore: Bean properties....observe and make inferences. Test with heat and light. Finish book Math: Intro into perimeter	Science: Hot/Cold – How does temperature effect loco beans? Math: Estimate number of bean jumps in one minute. Create a fences to contain a loco bean. How can you measure the perimeter?	Engineering: ASK: Can you design a tool to help farmers gather loco beans effectively? Engage: Show a tub with plants and seeds on the ground. Need a tool to pick up the seeds off the ground. Imagine: Show materials. Have five minutes to sketch several possibilities. Share with across neighbor. Share with neighbor behind you. Plan: Share ideas with your partner and plan in	Engineering: CREATE: Build your tool TEST/ReTEST: (incorporate math when they count how many beans they collect. Subtraction when they compare how many beans they collect each time) Tell students final test in front of class on Friday. Writing: Write a persuasive paragraph selling your tool to a farmer.	Engineering: Science Showcase: Show your design and tell how it works.

Integration of the Engineering Laboratory

The collective analysis of the data supported that the GES engineering laboratory is a primary component of the school's implementation of STEM curricula. The students in the laboratory applied science, technology, engineering, and mathematics concepts to solve real-world problems that also reflect parts of the curriculum for one or more content areas. GES students attend four one-week-long engineering laboratory sessions per year. Each occurred during the nine-week grading period during the regularly scheduled science class. Typically, about 50 minutes are devoted daily to science. However, during the STEM Block, the time may fluctuate to accommodate the laboratory's needs. The STEM specialist carefully designed the instruction to build on what is learned each week during an academic year. Each year provided a layer of authentic knowledge and skills necessary for subsequent yearly projects. By the time students complete fifth Grade, students appear to acquire an engineering mindset. The principal concluded, "If they've gone through our building from K [kindergarten] to fifth grade, they'll have gone through the 24 sessions, and you can see them emerge as with that engineering thing, understanding the engineering process." The STEM specialist trained teachers on the STEM lessons, including modeling how to facilitate student learning, behavior, and thinking like an engineer. Additionally, she worked collaboratively with teachers when facilitating and co-facilitating students in the laboratory. Engineering laboratory lessons were taught and facilitated by the grade-level science teacher, STEM specialist, and the engineering laboratory aide, who has worked part-time in this role for three years, helping students as needed.

Students worked through different parts of the EDP (e.g., ask, imagine, plan, create, improve, and communicate) throughout the STEM Block week. Posters explaining the process for each engineering phase were posted on the walls, referred to by educators, and used as anchors for student thinking and action. Throughout the weeklong laboratory, students were prompted to refer to these posters to help them through the EDP. The engineering laboratory facilitators prompted students to identify a problem and its possible solutions during the "Ask" phase. During the "Imagine" phase, students identified the possibilities, explored options, and agreed on the best solutions for their problems. Students created a "Plan" and determined the necessary materials to build their cargo boat. Next, students created a model and evaluated it to decide if they followed their plan and met their goal. Students tested their model at the end of the "Create" phase. During the "Improve" phase, students analyzed and appraised their model to assess whether or not it worked, explored what they could have done differently, and considered what would make it better. In the final phase, "Communicate," students discussed if changes were needed, listened to feedback from others, and determined whether the problem was solved. The laboratory experience appears to culminate in the necessary knowledge and skills students need to be successful engineers and provides a safe atmosphere where the EDP encourages students to make mistakes, learn, and redesign.

The specialist proudly shared, "The engineering lab has been key to the success" of Gemini Elementary, citing the STEM Block as a critical component of their success. Several teachers shared their beliefs that students demonstrated a shift in how they think and act due to participating in the engineering lab. One third-grade teacher noted, "[The] engineering lab like I said, it creates that mindset" for students to become an engineer. Students often work in groups of two to three. Students are expected to follow the EDP and communicate their results at the end of each STEM block. The following section describes how fourth-grade students worked through an EDP on buoyancy, offering an example of how the engineering lab is implemented at Gemini Elementary.

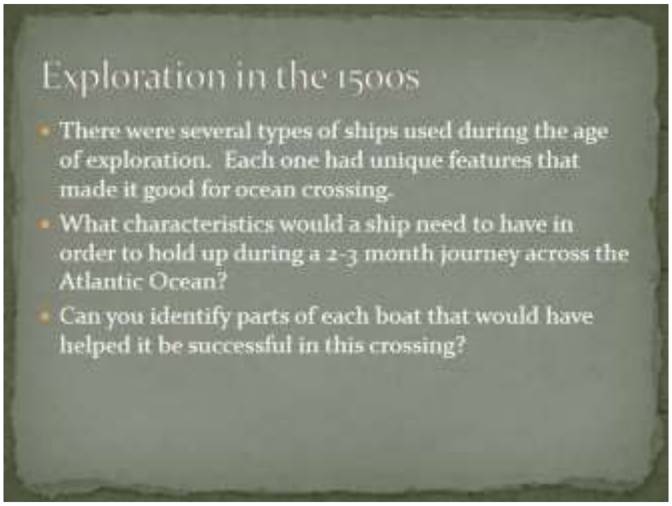
Cargo Boats EDP

According to the focus group data, the Science State of Texas Assessments of Academic Readiness (STAAR) Grade 5 data indicated that students struggled with the concept of buoyancy. Therefore, fourth-grade teachers chose the cargo boats EDP, which integrated social studies and science concepts. Science was the dominant content area used to develop this concept. Still, the inclusion of social studies helped deepen students' learning of the history of shipbuilding and how buoyancy was an important scientific concept that aids in thriving shipbuilding. The researcher observed the introduction of the cargo boat EDP for a fourth-grade class and all phases of the engineering of the cargo boat, except the "Final Testing" and "Communicate" phases. The STEM specialist described the final testing and communication phase experience was described to the researcher by the STEM specialist after completing the fourth-grade engineering laboratory. The teacher, the STEM specialist, and the engineering aide facilitated the project. The fourth-grade science teacher was absent during the Tuesday observation, so a fifth-grade teacher taught the engineering laboratory to the students. The fifth-grade teacher had prior knowledge about the cargo boat EDP but was asked to be a substitute in the engineering laboratory that morning. Therefore, the STEM specialist interjected and often took the lead in facilitating this project during the Tuesday observation. Additionally, there was an engineering laboratory aide who walked around to help students if they had questions. This section will explain how the teacher facilitates the EDP as students work through the EDP during the STEM Block.

Before beginning the EDP, the researcher observed the teacher begin the lesson with a PowerPoint titled "Ships for Exploration." During the presentation, students discussed how explorers would cross the Atlantic Ocean during the 1500s (Figure 3).

Figure 3

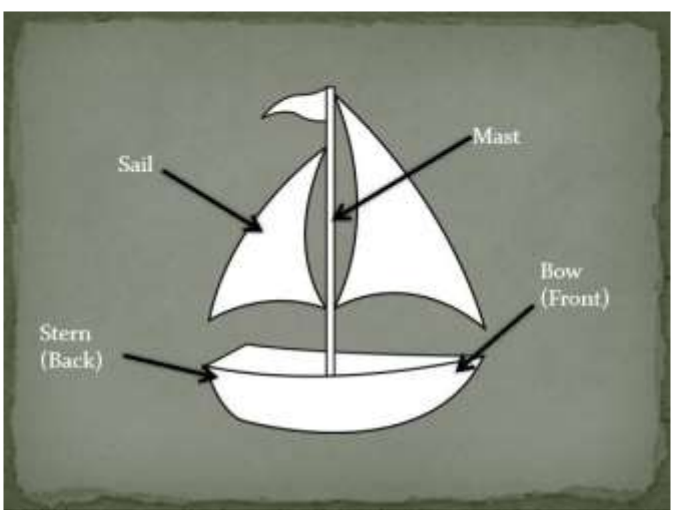
Engage Lesson on Exploration in the 1500s



The researcher noted that the teacher used a Think-Pair-Share instructional strategy with students to brainstorm what types of unique features ships would have to travel across the Atlantic Ocean for two to three months. "What features or characteristics of a ship are needed to withstand travel across the Atlantic Ocean?" the teacher asked. Then, as students looked at a generic diagram of a ship (Figure 4), the teacher discussed the essential features their ships would need in the EDP.

Figure 4

Diagram Explaining Parts of a Ship



Toward the end of the Ships for Exploration lesson, the researcher noticed the lesson shift from teacher-driven to student-driven EDP. The fifth-grade teacher and STEM specialist, who substituted for the fourth-grade science teacher, explained the project together. Both appeared familiar with the students and the project. Therefore, they could fully describe the expectations and facilitate students' ability to think and act like engineers. The teacher asked, "Can you design a ship that can carry a crew and cargo and withstand wind, rain, and waves in the Atlantic Ocean?" During this moment, the researcher noticed that students appeared to think about the problem and were shifting their mindsets to become cargo boat engineers. Students were then prompted to write the "Ask" question in their science journal (Figure 5). Next, detailed information aided the "Imagine" and "Plan" phases. The teacher showed students the materials list (Figure 6) for their cargo boat build and explained that the king allotted them a $10.00 budget. The teacher provided time for students to ask questions about the type and number of materials. According to the STEM specialist, question time reflects the brainstorming engineers do at the start of a project as they consider realistic options. The STEM specialist explained that the budget was for the prototype and the final design. She continued explaining that the boat should not sink, and they would "take a fan and blow on it" to simulate wind and test their design. Rainstorms would be simulated using a watering can, and typhoons/hurricanes would be simulated by shaking the poolside extremely hard. "[There will be] a massive rainstorm that will see if your boat can make it across the sea. This is what our explorers did," the specialist enthusiastically explained as she connected social studies and science.

Figure 5

EDP: Student Example of the Ask Phase

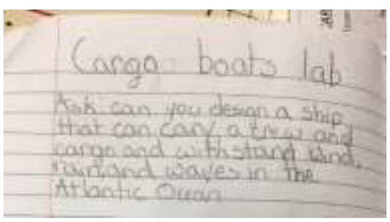


Figure 6

Cargo Boats Material List

Before an engineer designs a project, the specialist explains that the questions during the brainstorming session are used to imagine the design and weigh alternatives. During the next phase of the EDP, students were provided additional details and asked to "Imagine" what their boat needed to look like when traveling across the Atlantic Ocean (Figure 7). The researcher observed students sketching their ideas in their science journals as they were encouraged by the specialist not to worry about their budget constraints. The sketch had to be large and labeled with materials. Students were encouraged to look at the materials list. The specialist reminded students that the ship must carry a crew and cargo. The crew consisted of six miniature teddy bears and a cargo of 40 grams of clay. Students had five minutes to complete the "Imagine" portion individually (Figure 8). "Individual ideas only. No talking; by-yourself time," the specialist reminded students. Students continued transitioning from the teacher-centered instruction to a more student-centered "Plan" phase where the design was collaboratively constructed.

Figure 7

EDP: Additional Details Provided in the Imagine Phase

The researcher observed students share their ideas with the class in a whole group discussion and modeled a "think tank" atmosphere. At the end of five minutes, the researcher observed students sharing their ideas with their "A and B partners." Many students appeared to enthusiastically use their hands to explain their ideas and sketches to their partners and pointed to materials if needed.

Figure 8

EDP: Student Example of the Imagine Phase

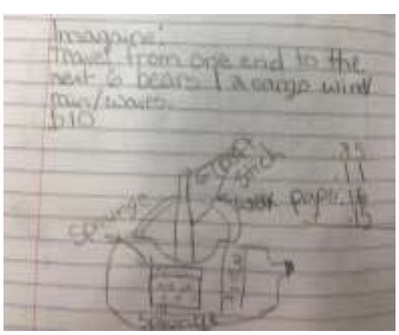
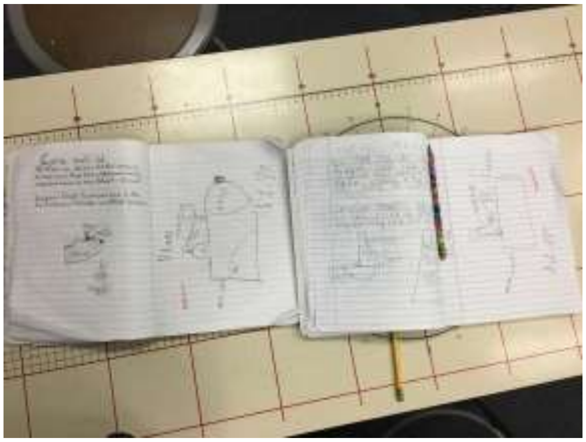


Figure 9

EDP: Student Examples of Approved Collaborative Plan



After sharing, students combined both designs and ideas and created a “Plan” with a new sketch on a clean sheet of paper in their science journals. The researcher observed groups receiving an approval stamp from either the teacher, specialist, or engineering aide after finishing the new design and completing the budget sheet individually (Figure 9). If needed, students were directed to the mathematics anchor charts in the back of the laboratory (Figure 10). The facilitators reminded them, "The king has told us you have $10.00 for this boat [so] stay within your budget." GES students acted as engineers and used specific constraints such as budget constraints that could impact their design. Completing their Cargo Boat EDP within the proper constraints provided students with a real-world application of correct budgeting and managing materials for their project.

Figure 10

Adding and Subtracting Decimals Review Anchor Chart

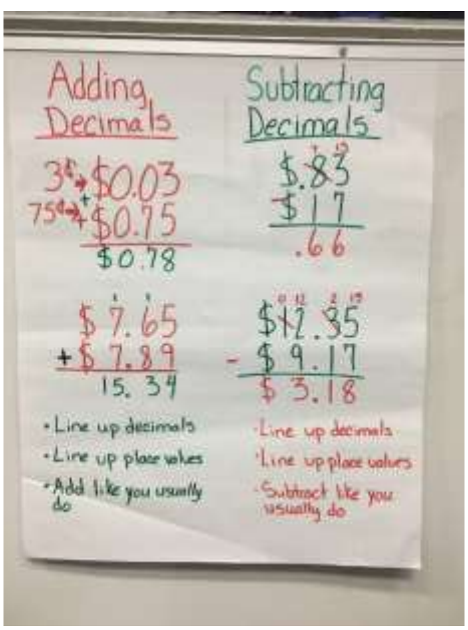
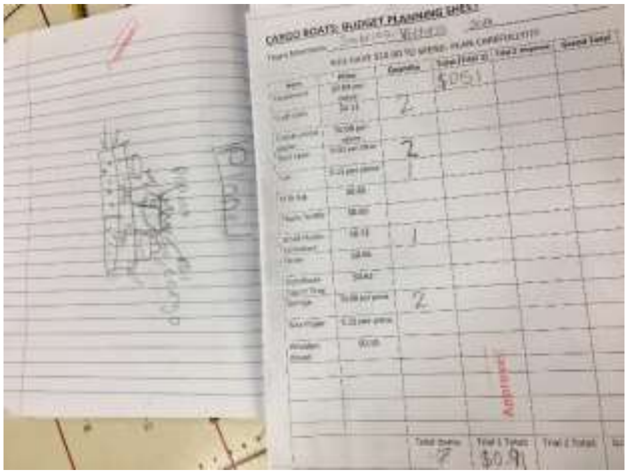


Figure 11

EDP: Approved Plan and Budget Sheet



The researcher observed that the "Create" phase began when students received approval for their "Plan" with the new design and budget (Figure 11). The researcher saw students beginning to review and collect materials as they began the "Create" phase (Figure 12). Using duct tape was permitted to build the cargo boat; however, students independently budgeted and measured the appropriate amount.

Figure 12

EDP: Students Review and Measure Materials to Create

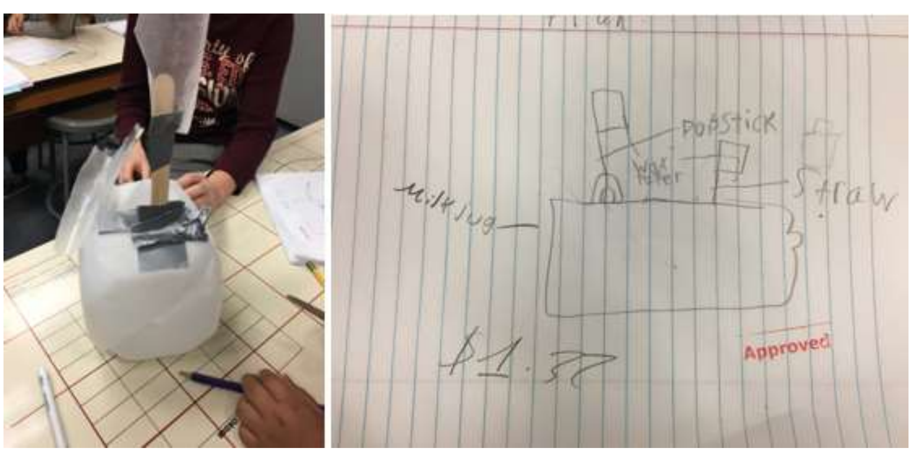
Using their design plan, the researcher observed students work collaboratively to build their cargo boats (Figure 12). They regularly communicated about the build's plan and reality as a check-and-balance and to ensure accuracy. According to the teacher and specialist, students' final products should match their approved designs (Figure 13). This phase marked an apparent move to a student-driven environment with students thinking and acting more like engineers.

Figure 13

EDP: Students Create Their Cargo Boats

Figure 14

EDP: Approved Plan and Built Cargo Boat Comparison



Students tested their cargo boats in a small plastic pool (Figure 15). As stated, the teacher provided "extreme weather conditions," utilizing a fan for wind, a watering can for rainstorms, and shaking the side of the pool for typhoons and hurricane waves. During testing, the teacher and STEM specialist prompted students to think about how they could improve their designs by analyzing what worked and did not. After testing, students were provided time to "Improve" and redesign their cargo boats and retest them. During the trials, students collected and placed data into an Excel spreadsheet.

Finally, students shared the results of their designs. The researcher did not observe students during the "Communicate" phase; the STEM specialist provided information on what students completed during this phase and the grading rubric for students' presentations. She said the students wrote a persuasive letter to the king asking him to fund their expedition, which included the ship's design and how well it held up to severe weather conditions, thus allowing it to cross the Atlantic Ocean. The final presentation included a skit in which they presented their cargo ship to the king (Figure 16). Students used the Oral Presentation Rubric: Presentation to the King (Figure 17) to guide them.

Figure 15

EDP: Testing Extreme Weather Conditions

Figure 16

EDP: Students' Final Cargo Boats

Figure 17

Example of Oral Presentation Rubric: Presentation to the King

CATEGORY	4	3	2	1
Preparedness	Student is completely prepared and has obviously rehearsed.	Student seems pretty prepared but might have needed a couple more rehearsals.	The student is somewhat prepared, but it is clear that rehearsal was lacking.	Student does not seem at all prepared to present.
Speaks Clearly	Speaks clearly and distinctly all (100-95%) the time, and mispronounces no words.	Speaks clearly and distinctly all (100-95%) the time, but mispronounces one word.	Speaks clearly and distinctly most (94-85%) of the time. Mispronounces no more than one word.	Often mumbles or can not be understood OR mispronounces more than one word.
Volume	Volume is loud enough to be heard by all audience members throughout the presentation.	Volume is loud enough to be heard by all audience members at least 90% of the time.	Volume is loud enough to be heard by all audience members at least 80% of the time.	Volume often too soft to be heard by all audience members.
Posture and Eye Contact	Stands up straight, looks relaxed and confident. Establishes eye contact with everyone in the room during the presentation.	Stands up straight and establishes eye contact with everyone in the room during the presentation.	Sometimes stands up straight and establishes eye contact.	Slouches and/or does not look at people during the presentation.
Listens to Other Presentations	Listens intently. Does not make distracting noises or movements.	Listens intently but has one distracting noise or movement.	Sometimes does not appear to be listening but is not distracting.	Sometimes does not appear to be listening and has distracting noises or movements.

The researcher witnessed fourth-grade students acquiring authentic, real-world learning experiences through observational data as they designed cargo boats in the engineering laboratory. She witnessed the teacher and STEM specialist work in tandem to facilitate the project and encourage the type of behavior and thinking required in each phase of building and evaluation of the cargo boat. Throughout the project, she observed students move from a teacher-centered introduction to a student-centered, authentic working environment, demonstrating a shift toward engineering behavior and thinking practices. The fourth-grade cargo boat STEM Block learning experience exemplified the integration of STEM curricula.

Discussions

STEM Specialist

One of the most important findings of this study uncovered the importance of the role of the STEM specialist when developing and implementing the instructional design of the engineering laboratory at GES school. Educator comments revealed that the STEM specialist assumed the role of the EDP's lead facilitator in the engineering laboratory during the initial implementation. Unlike the study by Hammack and Ivey (2019), which concluded that teachers would not implement engineering concepts into their classroom due to a lack of knowledge, this study indicates that teachers acquired a deeper understanding of the STEM content and pedagogical knowledge and skills needed to be a successful facilitator of EDP by participating in team planning and watching the STEM specialist model lessons. Since it is challenging for students to connect STEM content areas and real-world applications (Breiner et al., 2012), teachers should learn how to facilitate EDP to foster these explicit connections. AT GES, this was done by the specialist modeling best practices while she taught the EDP lessons to the students and inviting the teachers to begin co-teaching EDP lessons. This gives teachers an understanding of how students can acquire 21st century skills (P21, 2015). The content specialist can exemplify how to provide students with an in-depth learning experience that could spark students' sense of curiosity and interest. A hands-on approach helps educators understand the content and could give students a more incredible foundation in STEM concepts (Margot & Kettler, 2019) and possibly increase their interest in STEM careers (Tanenbaum, 2016). Providing teachers with modeling opportunities could guide and increase their STEM content and pedagogical knowledge and skills when facilitating an EDP. As teachers' confidence increases during the facilitation of the engineering week, then they may feel more comfortable implementing EDP strategies in their classroom.

Team Planning

Another significant layer of instructional design included the importance of teacher collaboration during team planning of the EDP lessons. Teachers could share new ideas and help colleagues connect across cross-curricular content areas with increased practice. This essential part could help teachers expand their thinking of STEM fields and ways to include modern real-world problems (NSTA, 2021). Therefore, team planning could be an essential time where teachers share their ideas and collaborate on ways to improve their lessons, integrate modern STEM concepts, make explicit connections to STEM in classroom instruction, and create a budget for the different EDP. Dym et al. (2009) support the integration of different STEM concepts, including budget constraints. Since students fail to understand STEM interdisciplinary connections (Breiner et al., 2012), educators need to discuss them during instructional design and planning. Experienced teachers and content specialists could explain and model new teachers' classroom content and EDP lessons. In addition, STEM integration was not limited to science, mathematics, engineering, and technology but included English and language arts, social studies, and fine arts. This supports the notion by Sanders and Wells (2005) that the intentional integration of STEM areas can lead to the connections of STEM into the instruction of non-STEM classes. The purposeful collaboration helped teachers to be consistent across grade levels and cross-curricular content teams. These collaboration opportunities are often overlooked due to the stress elementary teachers may feel from teaching multiple disciplines and high-stakes testing (Hammack & Ivy, 2019). Therefore, the additional time allotted to teachers during planning is essential for the success of the STEM program.

STEM Block

In addition to instructional design, this study indicated that the engineering laboratory is the root of the successful implementation of STEM at GES. The primary tool for integrating STEM education was the STEM Block, which included a weeklong EDP where students attended and studied in the engineering laboratory. At GES, the STEM Block provided students with a safe place to act like engineers to brainstorm different engineering designs and solutions. Gormley and Boland (2017) concluded that using an interdisciplinary approach that allows students to brainstorm solutions promotes creativity and ingenuity. Using an integrated approach to teaching STEM supports students' ability to make connections, improving their learning using the EDP (NRC, 2014).

Furthermore, Lippard et al. (2019) agree that EDP is a natural way to apply engineering habits of mind. These support this study's findings that all the educators who participated agreed that the engineering laboratory was the most effective way to integrate all aspects of STEM into their elementary school. The engineering laboratory could create an environment that allowed for the teaching of the engineering processes and was an encouraging space for students to possibly shift their mindsets and become engineers. This environment may foster students' productive struggle when faced with challenges and supports an engineering culture and framework (Kapur & Bielaczyc, 2012).

Creating an Engineering Culture

The findings indicated that implementing integrated STEM curricula into an elementary school benefited the students and educators. GES's vision of creating a STEM elementary school where students were encouraged to make mistakes, learn, and redesign, created a school culture that embraced failure. Peters-Burton et al. (2019) supported the importance of failure as part of the learning practice for teachers and students. Wendell et al. (2017) noted that, when properly scaffolded, reflective decision-making is crucial when participating in engineering design. Waters and Orange (2022) expands on this notion to include adopting a STEM-driven school culture encompassing engineering aspects and habits of mind. A STEM-driven mindset could be an essential aspect of including not only during an engineering STEM Block but also throughout daily activities in classrooms. Encouraging students to reflect on why their design was ineffective and prompt them to improve, redesign, and retest their design could be foundational to supporting this STEM-driven school culture. This instills a culture that promotes engineering habits of mind (Loveland & Dunn, 2014). This culture and approach could provide a safe environment that accepts failure as a natural part of learning and where students' interest and engagement could increase to the integrative nature (English, 2016).

Maiorca and Mohr-Schrodder (2020) posited that creating authentic learning experiences that provide real-world connections and applications of 21st century skills enables students to be immersed in an engineering environment. English (2021) also believed that these 21st century engineering skills solidify students' STEM knowledge and application. Furthermore, collaboration and communication among students with adults and peers can be enhanced during stages of the EDP. Students could improve their communication skills as they work through different steps in the research process. In addition, students should be encouraged to find ways to solve problems and collaborate with others in the classroom and engineering laboratory. These are essential 21st century skills that are foundational and transferable to multiple areas across the STEM fields (English, 2019; P21, 2015).

Implications

This study also indicated that it is essential for principals to invest in personnel, a STEM content specialist, and resources. Furthermore, the STEM specialist must develop teachers' STEM content and pedagogical knowledge and shift their thinking from co-facilitating an EDP to facilitating the EDP during the engineering week. This shift could help build teachers' confidence and skill set. Providing teachers with adequate time throughout the school year to network and collaborate with other STEM educators during planning days and other professional opportunities should be considered. This could support the STEM school culture where students and teachers believe it is acceptable to make mistakes, learn, and redesign (Waters & Orange, 2022). This mindset creates the idea that learning in the classroom and the engineering laboratory after mistakes are made is then enhanced by redesigning and reworking ideas and providing students and teachers a safe environment. Mindset-related implications often influence how students and teachers are willing to take risks and try new designs and ideas. Thus, it is suggested that school leaders, especially principals, create an environment that embraces a STEM-driven school culture (Waters & Orange, 2022) that empowers teachers, promotes innovation and sharing of ideas, and instills engineering habits of mind into students and faculty.

Conclusion

With a deficit of literature regarding STEM initiatives and case studies (Lesseig et al., 2019; Peters-Burton et al., 2019), this study provides insight into effective practices for integrating STEM into an elementary school. The role of the STEM special was critical to the development of the initial STEM Block lessons and the teachers' STEM content and pedagogical knowledge. Based on educator comments and researcher observations, the engineering laboratory appeared to be a natural integrator for STEM concepts and a key component of Gemini Elementary's perceived success. It created an environment for teachers to develop and hone their STEM content and pedagogical knowledge by watching and co-teaching with the STEM specialist. Additionally, it provided an engaging learning environment for students to utilize and improve their 21st century skills as they enthusiastically took the role of a ship designer. Furthermore, the engineering laboratory was a dedicated setting for the purposeful STEM integration for every student from all grade levels to attend and practice vital engineering habits of mind.

Limitations

This school was purposely selected due to the implementation of integrated STEM curricula and tried to identify critical components of the school's success. With the study conducted at a STEM school, the participants might have displayed possible bias that would showcase their STEM elementary school as being successful. This might have been due to the initial phrasing of the survey question asking what key components of a successful STEM school were.

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