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Research Article

STEM-driven school culture: Pillars of a transformative STEM approach

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Educators are vital in capturing students' STEM interest. An integrated approach to STEM education is necessary to promote students' interest and curiosity while building the foundation of STEM concepts needed to fuel the STEM workforce. This exploratory case study examined K-5 STEM educators' perceptions of a successful STEM elementary school. Survey, interview, and focus group data were analyzed and coded to determine what educators feel are the components of a STEM elementary school. This paper focuses on the emergent themes of a (a) STEM-driven school culture and (b) collaboration and professional development. By working collaboratively, educators at Gemini Elementary School developed a STEM-driven school culture that encouraged students to embrace a growth mindset and learn from their mistakes. Teachers were supported in their learnings by the STEM specialist, administrators, their colleagues, and grew their knowledge by attending professional development sessions. The results of this study point to the need for a paradigm shift where embracing a STEM-driven school culture can provide an explosion of academic and creative freedom.

Keywords: STEM school; School culture; Case study; STEM education

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1. Introduction

Integrating science, technology, engineering, and mathematics (STEM) into school curricula and programs is often perceived as a solution to meet the projected deficits in the United States STEM workforce. The rapid advancement of innovations and technologies are two of the driving forces that are prompting industries to upgrade job requirements to include 21st century skills and an in-depth STEM knowledge (Granovskiy, 2018; Miller, 2017; Shernoff et al., 2017). Increased pressure is being placed on U.S. educational systems to provide K-12 students an opportunity to acquire 21st century skills such as critical thinking and problem-solving that transcends to other areas (Partnership for 21st Century Learning, 2009). Since it is perceived that citizens with STEM backgrounds could sustain the future workforce, early exposure to STEM concepts in elementary school might provide a lasting impact on the U.S. economy and its citizens.

Elementary students with an integrative STEM curriculum calls for innovative school leaders who create a school culture through a collaborative vision (Stolp, 1974) and develop teachers'

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STEM capacity with educator supports (e.g., professional development and instructional design) that target their development of STEM content and pedagogical skills (Rigby et al., 2017). This is particularly important as, elementary school teachers are perceived as having a lack of STEM content knowledge and skills (Hammack & Ivey, 2017; Watson et al., 2022). Positive school cultures are developed over time through routines and represent the educational practices of the school (Erickson, 1987). Embracing a culture that accepts and promotes students' understanding of academic risk-taking and productive failure challenges students (Kapur & Bielaczyc, 2012) and is a key element of STEM practices such as the engineering design process (EDP). Understanding how school culture is developed and supported could be important to understanding STEM educators' perceptions of successful schools.

STEM schools are one mechanism to capture students' interest and engagement in integrated STEM opportunities and introducing them to different STEM careers. With the limited research regarding STEM schools, Lesseig et al. (2019) advocate for additional STEM school case studies be conducted to create common frameworks, language, and knowledge for educators. With STEM education perceived to be a possible solution and the limited literature regarding STEM schools, this study sought to identify key components of a successful STEM elementary school in Texas. The following research question was explored in this study: What are K-5 STEM educators' perceptions of a successful STEM elementary school?

2. Literature Review

2.1. U.S. Economy and Workforce

Economic trends suggest a demand for a STEM education focus. Top jobs in the United States will require substantial science or mathematics training, and computer and mathematical jobs continue to be two of the fastest growing STEM work groups (Beede et al., 2011; The U.S. Bureau of Labor Statistics [BLS], 2020). BLS projects that between 2016 and 2026, science and engineering jobs will increase by almost 900,000 (Sargent, 2017). To meet the needs of engineering industries (e.g., automotive, computer science, construction, energy, and environmental), workers and engineers will need to be equipped with advanced 21st century skills (Subramanian & Clark, 2016). Science, technology, engineering, and mathematics (STEM) jobs are predicted to reach over 10 million occupations by 2030 (BLS, 2020). Therefore, providing U.S. citizens with STEM knowledge and skills may help them obtain high quality jobs that fuel national and global economies.

Stakeholders such as government organizations, businesses, and education are promoting STEM education hoping to increase its interest to educators and students (Cunningham et al., 2015; National Science Board [NSB], 2007; President's Council of Advisors on Science and Technology [PCAST], 2012) because of STEM's potential to shape the future. Shernoff et al. (2017) posited that STEM innovations not only influence the US economy but also the standard of living of its citizens. To cope with rapid changes in technology and development, businesses have been compelled to rapidly adjust their training requirements to include solution oriented critical thinking and problem-solving skills that meet the needs of addressing multifaceted 21st century challenges (Miller, 2017). Meeting these technological advancements requires human capital to be built in the STEM workforce; thus, it is imperative to equip citizens with 21st century skills that provide an in-depth knowledge of STEM concepts (Granovskiy, 2018). Pressure is placed on education systems to train educators and students to be flexible in their thinking and respond quickly to technological advancements (Haddad & Draxler, 2002).

Providing students with an in-depth STEM background affords greater opportunities for them to thrive in a global STEM workforce and a successful economic future. Increased STEM opportunities positively influence students' attitudes and confidence towards pursuing STEM careers (Wang, 2013). Deficiencies within the U.S. educational system may hinder economic growth by not preparing US students' adequately for upcoming STEM jobs, limiting opportunities to citizens (Rozek et al., 2017). Capturing students' early interest in STEM concepts is foundational to equip them with the STEM knowledge and skills that will afford them the opportunity to participate in the STEM workforce and meet the needs of rapidly changing scientific and technological society (Tanenbaum, 2016). Thus, preparing elementary educators to teach STEM concepts that utilize engaging, practical, real-world applications could lay a strong STEM foundation for future generations.

2.2. Challenges of STEM Education

However, obstacles exist to implementing STEM curriculum into education systems. Multiple interpretations of STEM concepts such as STEM curriculum and STEM integration limits implementation of STEM education in public schools, which reduces the number of students entering the STEM careers (Honey et al., 2014; Schneider et al., 2016). According to the National Research Council [NRC], "there are many reasons to be concerned about the state of STEM learning in the United States in the face of research that suggests that many students are not prepared for the demands of today's economy and the economy of the future" (NRC, 2011, p. 3). Teachers in elementary and middle schools may not be prepared due to limited STEM content knowledge educators (Brophy et al, 2008; Hammack & Ivey, 2017; Watson et al., 2022). Lesseig et al. (2019) noted elementary teachers may not be as prepared to teach in STEM schools. Watson et al. (2022) supported this notion and stated many elementary teachers lack the STEM content knowledge. Additionally, elementary teachers' reluctance to implement STEM curricula might be due to teaching multiple content areas and not having adequate time to plan and implement topics that are not assessed in standardized testing (Hammack & Ivey, 2019). This supports the perception that elementary educators view STEM aspects such as engineering as a nonpriority for their schools due to administrators' focus on "state mandated assessments and reading" (Hammack & Ivey, 2019, p. 516). Results such as these are often viewed as obstacles to incorporating STEM curricula into schools and might hinder the success of STEM initiatives throughout the U.S.

2.3. Integration of STEM Education

Utilizing an integrated STEM curriculum and programs in elementary and secondary schools can provide students with many long-term benefits (Watson et al., 2022). With STEM education awareness increasing, educators are better equipped with hands-on, rigorous, and real-world STEM activities and their role in providing the necessary foundation in STEM learning and achievement (Margot & Kettler, 2019). The report *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*, from the National Academy of Engineering and Board on Science Education of the National Research Council identified, discussed, and investigated integrated STEM initiatives in the US K-12 educational systems and provided common perspectives and vocabulary that researchers and practitioners could utilize (Honey et al., 2014). Supporters of this approach argue that teaching STEM across disciplines in a fully integrative approach provides the opportunity for teachers to connect different disciplines to real-world problems which helps solidify students' understanding and learning (Honey et al., 2014; Subramanian & Clark, 2016). 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). Rose et al. (2019) noted that planning of curriculum and instruction, providing professional development, and creating infrastructure and programming contributed to successful integration of STEM.

Erdogan and Stuessy (2015) posited that exposure to STEM curriculum benefits all students academically and socially, even if they do not pursue a STEM career in college. Applying an integrated approach builds the STEM skills needed in general and prepares students to be better equipped to major in STEM careers; thus, attempting to keep the STEM pipeline intact (Smith et al., 2015). Thus, an integrated STEM approach in education could be a strategy which allows students to learn about global real-world issues and create interdisciplinary solutions that address complex problems (English, 2016; Honey et al., 2014; Sanders, 2008; Tsupros et al., 2009).

2.4. STEM Schools

As STEM initiatives gain momentum throughout the US, school districts are looking at ways to implement STEM into their schools, programs, and curricula. The purpose of STEM schools is to "provide STEM curricula for all its students" (Winsnall et al., 2014, p. 95). The school's design can be selective, inclusive, or provide STEM curricula through career and technical education (NRC, 2011). School districts looking to integrate STEM typically go through a methodical process that often starts with the notion that STEM could be a perceived solution to a problem within the district and form an exploratory committee to begin looking at different possibilities (Wieselmann et al., 2021). Wieselmann et al. (2021) emphasized the importance of hiring a STEM coordinator, placed at the elementary school, who can provide professional learning and support to teachers that guides them on instructional best practices. Additionally, the findings of this study indicated that providing staff with planning days where substitute teachers covered their classes was essential to implementation (Wieselmann et al., 2021).

Using a list of 20 eSTEM components, a case study conducted by Peters-Burton et al. (2019) sought to identify critical components that were present at Walter Bracken STEAM Academy, a nationally recognized eSTEM school, and explore possible new emergent components. The findings of this study reported that 19 of the 20 critical components were present at Bracken and identified four emergent components concluding that early exposure to STEM is essential to student learning. In addition, findings indicated STEM is a way to address different ways of thinking that creates dynamic learning environments focused on innovation and inquiry (Peters-Burton et al., 2019). This study indicated that a STEM-focused elementary school's success is due to teachers' willingness to expand their content and pedagogical knowledge that allows them to hone their practice while they try new approaches to student learning. STEM-focused elementary schools could be more successful when they are in a STEM-driven school district that promotes STEM vertical alignment throughout K-12 schools (Wieselmann et al., 2021).

With the exception of the two studies described above, little literature exists regarding STEM-focused elementary schools (Peters-Burton et al., 2019). According to Tanenbaum (2016), "introducing students to STEM early in their education, in both informal and formal learning settings, capitalizes on children's innate interest in the world around them" (p. 44). Making connections between STEM disciplines could promote students' interest and curiosity (English, 2016) while building the foundation in STEM concepts needed to supply the STEM workforce with properly skilled employees. Osborne et al. (2003) suggest students' attitude towards science can be impacted in elementary school. Peters-Burton et al. (2019) suggested that elementary schools can make explicit connections between science learning and literacy skills which might help "capture students' interests in STEM before such interests tend to drop" (p. 447). STEM elementary schools provide early exposure to students that may provide the foundation needed for students to make connections between disciplines and real-world experiences.

2.5. STEM School Leadership

The success of schools and school initiatives are often the result of a strong leadership team (Fullan, 2003). Leaders should provide organizational structure that supports and promotes teachers' innovation that improve their professional practice and student learning outcomes (Peters-Burton et al., 2019). Peters-Burton et al. (2019) noted "Prominent STEM design components included school leadership with clear vision, collaborative and empowered staff, as well as teachers open to innovation and continual learning" (p. 453). Similarly, the Principals as STEM Leaders [PASL] project supported the idea that school leaders need a clear vision but added that the leaders establish rational trust and demonstrate a commitment to STEM by "walking the walk" (Falloon et al., 2021, p. 110). A study conducted by Rose et al. (2019), shared the importance of the principal including all staff members in the discussion of the school's vision and trajectory. Lynch et al. (2018) concluded proactive, solution-oriented leadership strengthens the school vision while supporting teachers and students through open communication and positive interactions with leadership.

The principal is often seen as one of the most influential school leaders. Falloon et al. (2021) stated school leaders such as principals are imperative to the development of STEM initiatives; whereas Rose et al. (2019) noted "the catalyst for transformative paradigms and praxis are school administrators and teacher leaders" (p. 43). McKay et al. (2018) emphasized the importance of "empowering teachers as codesigners and coleaders of professional learning opportunities for other teachers" and indicated it was an important way of affecting change within a school (p. 60). These leaders can have a greater impact on other educators as they present at national and state conferences (McKay et al., 2018).

Providing students with high-quality learning has prompted a shift in school administrators' roles in the district and on campus. This shift was a result of the need to address instructional issues within schools and moved administrators from managers to instructional leaders (Rigby et al., 2017). As instructional leaders, school administrators impact adoption and implementation of new initiatives such as STEM-related programs (Watson et al., 2022). Wieselmann et al. (2021) proposed that STEM school leaders viewed STEM through an instructional lens and encouraged teachers to collaborate when developing STEM lessons and make explicit connections to STEM content and application. According to Peters-Burton et al. (2019) school leaders can have a significant impact by including teachers in the decision-making process and providing them autonomy in their classroom and PLCs. Collaborative experiences such as these are important to the sustainable integration of STEM education that affords all students the same opportunity (El Nagdi et al., 2018; Fairweather, 2008). Rigby et al. (2017) posited that the whole instructional leadership team should work together to increase teachers' professional capacity through coordinated efforts including professional learning and teacher workgroups such as PLCs. Nurturing teachers' STEM awareness and capacity can be accomplished through meaningful professional learning experiences that emphasize STEM interactions for K-12 students (Watson et al., 2022).

2.6. School Culture

Successful schools provide a clear vision, a collaborative and supportive climate, and additional planning time for teachers (Lesseig et al., 2019). A school's vision can be seen in its climate and culture. School climate, which is defined as "the quality and character of school life, and reflects(s) norms, goals, values interpersonal relationships, teaching and learning practices, and organizational structures" (Cohen et al., 2009, p.180) and school culture can support or hinder new initiatives like integrating STEM curricula into a school. Hierck and Peterson (2018) believed the school climate mainly focuses on emotional experience. Johnson et al. (2016) concluded that school climate is developed through scheduled, collaborative efforts that allow teachers planning time and engaging with STEM experts. Erickson (1987) noted that culture represents knowledge and provides meaning and believes, in schools, that culture "reveals the actions and underlying assumptions in the conduct of educational practice that might go unnoticed" (p. 23). School culture can also be a product of leaderships' organization that influences the norms and values of the school (Schein & Schein, 2017). Hierck and Peterson (2018) posited school culture is reflective of "positive behavior management practices" which can "increase student engagement to improve academic performance" (p. 3). Through collaborative and deliberate efforts, school cultures evolve over time due to routines and school traditions and are thought to be a key characteristic of STEM schools (Hierck & Peterson, 2018; Lynch et al., 2018; Peterson & Deal, 2011; Stolp, 1974).

Many times, school cultures can be attributed to principals and other school leaders. Principals who face new challenges by adapting their vision to meet their new needs often develop strong school cultures (Stolp, 1974). Having a vision that includes access to learning experiences for all students is important and "the most effective change in school culture happens when principals, teachers, and students model the values and beliefs important to the institution" (Stolp, 1974, p. 3).

Holmlund et al. (2018) were troubled by the notion that many students were not represented and afforded STEM educational opportunities and stated, "it has been apparent in education that when equity is not explicitly named and addressed, it is overlooked" (p. 16). Therefore, providing STEM learning opportunities to all students should be a goal of new initiatives and included in the school leadership's vision.

Positive school cultures can contribute to students' ability to thrive in schools (Fullan, 2007). Acceptance of an innovative way of thinking and acting produces confidence that encourages a culture of risk-taking and accepting failure. El Nagdi et al. (2018) proposed that teachers can also exhibit risk-taking characteristics that provide them and their students opportunity to learn. In an analysis of school culture in STEM schools, Lesseig et al. (2019) stated that teachers need to foster risk-taking behaviors and promote curiosity and inquiry among themselves and students. In the systematic review analyzing learning from failure, Jackson et al. (2021) noted, "teachers need to foster a classroom culture that embraces failure and learning together" (p. 12). This study revealed students should experience a safe learning environment where the teachers use instructional design methods that include productive failure and build trust amongst students and teachers. Thus, school culture can be supported in many ways including leadership actions and values, routines and traditions, utilization of productive failure, and embracing a STEM mindset.

3. Methodology

This exploratory case study (Creswell, 2007; Lichtman, 2010) examined K-5 educators' perceptions of STEM education and STEM schools. We selected Gemini Elementary STEM school (GES), a pseudonym for a suburban elementary school in Texas, as the site for this study because it was in its fourth year of integrating the STEM curriculum, which included an engineering design process (EDP) STEM Block. The study addressed the following research question: What are K-5 STEM educators' perceptions of a successful STEM elementary school? A case study was an appropriate qualitative framework to utilize because selecting one school to study allowed the researchers to explore educators' perceptions in-depth, with attention on the site context that framed their experiences (Lichtman, 2010).

3.1. Participants

We asked 44 GES K-5 STEM educators 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' learning experiences. Educators volunteered to participate in the study's K-5 STEM Educators' Perception Survey, focus groups, and/or interviews. Thirty-nine percent (n=17) of teachers and content specialists who were emailed the survey completed it. Survey participants included two content specialists, two kindergarten, two first-grade, one second-grade, three third grade, and four fifth-grade teachers, and three teachers who reported that they taught multiple grade levels. Twelve survey participants were White, one African American, three Hispanic, and one did not report their ethnicity. The participants' ages ranged from 25 to over 55

All K-5 educators were invited to participate in the focus group sessions. Due to time constraints, 16 chose to participate; eight of the 16 also completed the survey. We also conducted interviews with the STEM specialist, librarian, and principal. In addition, a follow up interview was conducted with a second-grade teacher to provide a deeper understanding of STEM at GES. The teachers, STEM content specialist, and librarian are female, and the principal is male. Survey, focus group, and interview participants provided the researchers with the last four digits of their phone number. The researchers were able to cross reference the data and identify focus group and interview participants who also completed the survey. Table 1 presents pseudonyms of educators who participated in the survey, focus groups, and interviews.

Table 1
Focus Group and Interview Participant Roles and Pseudonyms

Campus Position	*Role or Grade Level*	*Pseudonym*	*Survey*	*Focus Group*	*Interview*
Leadership	Principal	Mr. Petit			X
Team	STEM Specialist	Dr. DuBois	X	X	X
	Librarian	Ms. Jemison		X	X
STEM Teacher	Kindergarten	Ms. Fernandez	X	X	
		Ms. Bell	X	X	
		Ms. King		X	
		Ms. Lopez		X	
	1st Grade	Ms. Anderson		X	
		Ms. Bowe	X	X	
	2nd Grade	Ms. Lander		X	
		Ms. Spitz	X	X	X
		Ms. Lovett		X	
	3rd Grade	Ms. Shepard	X	X	
	4th Grade	Ms. Kennedy		X	
	5th Grade	Ms. Hudson		X	
		Ms. Neil	X	X	
		Ms. Cooper	X	X	

3.2. Data Collection

3.2.1. Survey

Using Qualtrics software, the researchers created the K-5 Educators' Perception Survey that focused on how teachers perceive STEM education, professional development opportunities, professional learning communities (PLC), lesson plan development, and key components of a STEM school (see Appendix). The 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 10 nominal items which included demographic questions. At the request of the principal, 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. The anonymous online survey took an average of 14 minutes to complete.

3.2.2. Rolling focus groups

Based on analysis of the survey data, the researchers wrote the focus group questions to provide a more in-depth explanation of STEM education and components of a successful STEM school. The principal and STEM specialist determined the focus group times, so they did not conflict with classroom instruction; we held these for 30 minutes during teachers' conference periods. Since they were presented as "come and go" as you can, they were called Rolling Focus Groups. The researchers emailed the STEM specialist a copy of the focus group questions, and participants received a paper copy during the session. There were 14 initial questions but due to the 30-minute time constraint, the researchers asked seven questions, two of which were used to identify participant responses (see Appendix). On the scheduled day, most teachers attended the focus group as a grade level team but some teachers came during their lunch break. There were seven focus groups with 16 participants (Table 1).

3.2.3. Interviews

We conducted semi-structured interviews lasting 20-40 minutes each. The researchers interviewed the principal on the phone and a STEM specialist and librarian on site. A follow up interview was conducted with a second-grade teacher to provide a deeper insight to the integration of STEM at

GES. We emailed a copy of the interview questions, focused on educators' perceptions of the elements of a successful STEM school, to participants prior to the interview to provide them with process time so they could formulate their responses.

3.3. Data Analysis

The researchers reviewed the data to look for possible trends prior to importing it into QSR International's NVivo10 qualitative data analysis software. Initial queries resulted in identifying high frequency words (e.g., STEM, engineering, science, students, technology, curriculum, teachers, technology, and math); this provided an overview of the data, but a more in-depth analysis was necessary to fully understand participants' perceptions. We ran text search queries to look for possible connections among topics relating to integration of STEM content. Additionally, we used an inductive coding process where we divided data into meaningful units based on auto-codes, patterns, and queries. Initial codes included professional development, exploratory phase, team planning, makerspace, communication, time, collaboration, STEM education approached, critical thinking, creativity, problem-solving, engineering, future improvement, real-world experiences, connections, and integration. Once coding was complete, we looked for common trends in the data, and also explored where the codes overlapped and could be possibly combined into themes. After importing the follow up interview data, the researchers looked for additional trends. Our analyses resulted in the themes presented in the following section.

4. Findings

Based on the survey, interview, and focus group data, seven common themes emerged from the larger 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 how the themes intertwined, we collapsed these initial themes into two major themes: (a) STEM-driven school culture and (b) collaboration and professional development for this paper.

4.1. STEM-driven School Culture

Gemini Elementary School's vision is to prepare and inspire lifelong learners to meet the challenges of a global society through critical thinking in STEM for generations to come. School administrators, teachers, and students adopted and adapted this initial STEM vision. Exploration of educators' perceptions of the key components that made GES a successful STEM school revealed that fostering a shared vision created a STEM-driven school culture and growth mindset for continual improvement. According to the participants, Gemini's STEM school culture/vision was one of the primary key components of a successful STEM school. A fifth-grade teacher supported this notion when she shared, "Well, I think that you've got to have administrators that are open-minded to new ideas and new approaches. And we have that." Every decision was made with STEM at forefront, thus cultivating a STEM-driven culture and teaching environment.

Understanding the history of how a STEM program began at Gemini Elementary School provides context and relevancy to its school culture. School district leaders became concerned about the diminishing student population at GES resulting from their decision to change the campus's boundary when a new elementary school opened, and beginning in the 2006-2007 academic year, the student population at GES decreased and the decline continued, making GES one of the smallest schools in the district. "The neighborhood around here started to grow older, and we weren't having as many kids coming to our school," the STEM specialist recalled. She said this prompted the assistant superintendent to ask the principal to "look at different things" to help increase the student population.

4.1.1. Fostering faculty buy-in

The principal cultivated a shared vision that resulted in faculty buy-in. To address the enrollment problem, the principal considered alternative school structures to increase student enrollment. He initially thought of creating a science magnet program at his school: "I started thinking about a magnet school because… our school was underpopulated by students and because of recent construction nearby with another school. And so, I really looked at maybe a science magnet." However, the district science coordinator steered him towards the idea of implementing a STEM curriculum instead. The principal recalled saying, "Let's start thinking about how we can be different as a school and really move our students in their thinking." He also shared with his faculty the idea of going in a different direction with their school and spoke with staff members individually and in team meetings. He felt that the teachers were delighted and felt their voices were heard. He recalled, "There was some excitement. So, we had a lot of different ideas." He continued, "And that's really, the buy-in part really came in through just really hearing them out." During a faculty meeting, staff members continued to brainstorm and discuss their options regarding a school transition. "The idea of a STEM campus emerged out of that conversation with the faculty," the principal noted. The principal and science coordinator began working together with the district assistant superintendent for elementary education and formulated more specifics about what a STEM program might look like.

Building on ideas developed in the faculty meeting, the principal formed an exploratory committee that included himself, content specialists, and teachers to investigate his vision of educating and preparing their students as 21st century learners. A fifth-grade teacher shared her perception: "Our administrators have been totally on-board, so I think just having the flexibility and kind of a vision [open-minded to new ideas and new approaches] is what's important." The students' acquisition of 21st century skills and STEM content knowledge was at the forefront of the discussions. The STEM specialist at the school, who was hired to help lead the STEM transition, reflected on this decision:

> And when we were planning the STEM program, there was nothing that we were planning that all kids couldn't benefit from, so we didn't understand why we couldn't have a school, a STEM school for everyone and then the magnet to attract other kids to our school, so we went that route.

The educators at GES approached the new school structure with a growth mindset driven by a STEM curriculum and focus. They continued to explore ideas for their STEM program and traveled to local school districts that had implemented different programs (i.e., STEM and science magnet schools) and collected ideas. The principal recalled, "So we really kind of did a lot of research on what it [STEM] is and then really started thinking about how we could apply those ideas." The district approved the proposed inclusive STEM school for all learners, which included a magnet school for select learners. The following August, the STEM program was implemented.

4.1.2. Cultivating a STEM-driven school culture

The school culture and motto, "We are here to make mistakes, learn and redesign," resonated throughout the school and was identified by GES educators as one of the key components. The STEM specialist believed in cultivating a safe environment where students are encouraged and supported to participate in academic and social risk-taking. She commented on her belief that students' creativity flourishes when they are academically successful:

> I see this creativity and spirit in kids. They want to be here. They like what they're doing. And so academically that carries over into a quest to approach problems [with] risk. They are willing to take a risk. They are willing to try academically, and that comes from the STEM program.

Her attitudes were shared by many of the teachers. For example, one kindergarten teacher stated that some of her students struggled in the beginning: "I see my perfectionist kids even at five have to overcome that hurdle of, 'That's okay that that didn't work the first time.'" As a kindergarten teacher, she felt it was important to begin teaching students that it is all right to change their thinking and try something different. At GES, learners work to continue to improve, thus instilling a growth mindset as a crucial element to the STEM-driven school culture, according to the participants

The notion of learning from mistakes and using those failures to improve was not just seen in kindergarten. The first- and fourth-grade teachers discussed an earlier conversation they had with each other the morning of participant interviews. The first-grade teacher recalled:

> The one thing you [the fourth-grade teacher] said in the morning was, mistakes is [are] how we learn. It's okay to fail. That to me is huge because so many want to be perfect all the time. The fact that you have an idea and you try it out, and then you go back and redesign and try again, that to me is the biggest part of their success. It's okay to fail, and it's okay to try again.

GES students are taught that making mistakes is a necessary part of learning which increases their confidence levels and motivates them to begin taking more academic risks. Furthermore, this mindset was extended and applied to everyday situations students may face. A second-grade teacher shared, "I mean when you're talking to kids about life in general, you've been making mistakes or not using kind words with a friend, you made a mistake, you gotta learn from it, then redesign your behavior to ger a more desirable outcome." This supported their school motto, "We are here to make mistakes, learn and redesign," and promoted the STEM-driven school culture that resonated throughout the school. Therefore, educators identified it as one of the key components that made the school successful.

Some of the teachers shared thoughts about growth mindset and how it is important that not just the students should learn that failure is necessary, but the parents as well. When discussing mindset in a follow-up interview, a second-grade teacher shared, "I think it's [growth mindset] just helped me to challenge those, especially students that may lack that confidence to push themselves, just letting them know that it's okay to make a mistake and we all make mistakes." She continued to elaborate on a student who "never has been successful in the lab" and the student told her, "I knew it was not gonna work." In a recent project, the teacher encouraged the student to not give up and continue redesigning and trying. "This is the most successful I've ever been," the teacher recalled the student saying. Examples such as this regarding growth mindset, students' resilience, and acceptance of failure were commonly shared during focus groups. Additionally, teachers felt that it is important that parents understand the importance of instilling grit and a STEM growth mindset in children. As one third-grade teacher noted:

> They [parents] have to be on board just letting their child be able to fail. And I think that's one of the biggest parts of it, is being okay with failure, and try again, and just really building that perseverance.

As evidenced in the above quote, some teachers felt that parents should promote the acceptance of making mistakes and learning from failure in a safe environment; thus, cultivating a growth mindset at home. The educators at GES believe that these experiences will prepare students to face challenging situations in the future.

The STEM-driven school culture naturally enfolded elements of trial and error, analysis, and continual improvement that are characteristics of integrated STEM instruction. Teachers also embraced the acceptance of failure as they tried new lessons for the classroom, science laboratory, and EDP STEM Block experiences. A fifth-grade teacher shared:

> I think willingness to let the teachers kind of play with it and let the teachers figure out what works and what doesn't work… Give them the freedom, because without that, there's no way that we would be doing anything that we're doing right now if they [administrators] hadn't really trusted us to kind of run with it and see what we come up with.

Thus, according to the teachers, the administrators' support and school culture provides the foundation for the mindset of making mistakes, learning, and redesigning and has students practicing this mindset throughout the day and in the engineering laboratory. Knowing that failure and risk-taking are part of learning, students' understanding of success could be transformed. Teachers' perceptions revealed that being successful now means that students exhibit resilience and persistence in their endeavors and do not give up. The development and nurturing of school culture promoted a STEM mindset and the sustainability of the vision for the Gemini STEM elementary.

4.2. Collaboration and Professional Development

The GES teachers identified teacher collaboration and professional development as being impactful in the development of their STEM-driven mindset, role as elementary STEM experts, and a sustainable shared vision. One first-grade teacher shared on the survey:

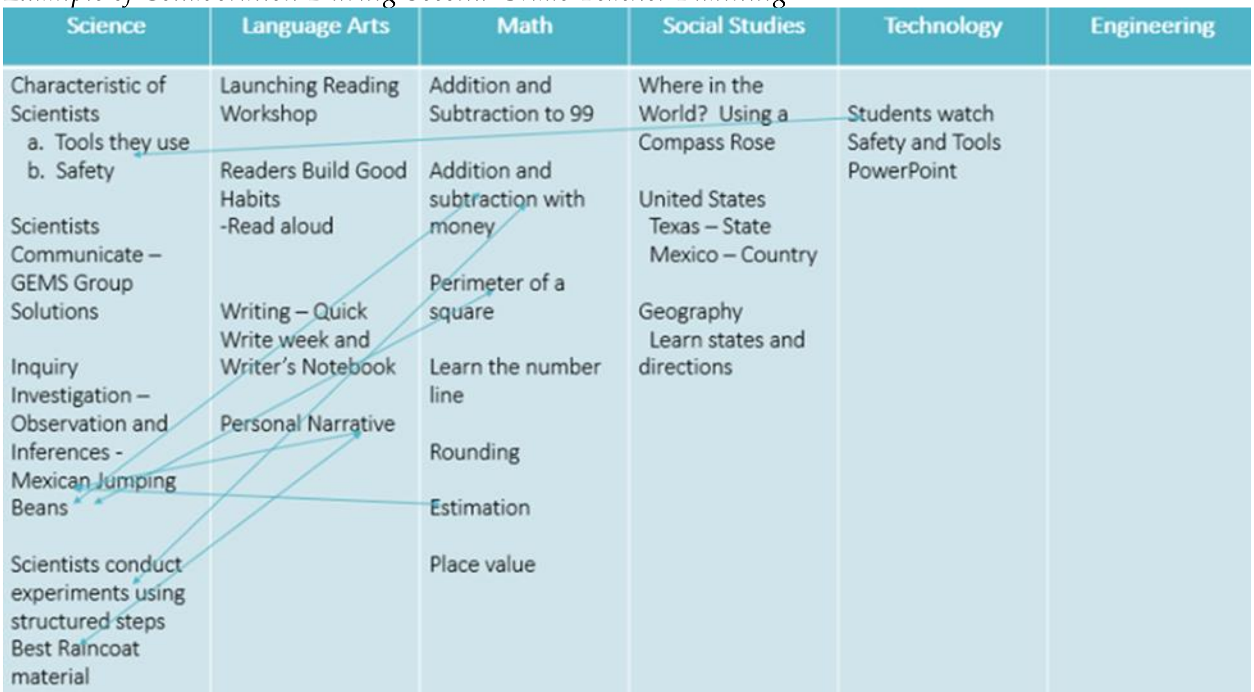
> Our wonderful science coach and the other coaches working together, encouraging us, and providing opportunities to learn more STEM activities, giving us the tools, we need to implement activities in our classroom and helping us in any way they can.

As evidenced by the data above, providing on-going coaching, instructional modeling, and discussion infused an added layer of continual professional development as teachers collaborated with each other and the STEM specialist to build an effective STEM learning environment. Furthermore, the principal valued building teacher capacity by expanding their depth of knowledge of STEM-driven instruction and school structure. In the survey, a third-grade teacher listed "teamwork", "collaboration", and "administrative willingness to put STEM in the forefront and promote it in every way possible" as key factors for making GES successful, thus, supporting that a variety of support systems were implemented at GES, providing teachers with opportunities to gain STEM content and pedagogical knowledge and skills.

When surveyed, teachers perceived teacher collaboration as one of the primary key components of a successful STEM school. School leaders encouraged educators to work as a meaningful team from the inception of the STEM School and they partnered to share knowledge, innovations, and lesson ideas. One teacher shared, "I have also notice how creative teachers can be when they plan with other teachers. The shared knowledge and ideas influences [sic] all classrooms." During interviews, teachers shared that they were encouraged to work together with horizontal grade level and vertical content teams by the school administration. All teachers were included in the collaborative efforts. For example, the music teacher believed that "collaboration between grade levels, disciplines, and specialties plays a huge role in our success. I support teachers with their units of study and they support my requests for rehearsal time." The researchers observed that teachers worked together in team planning meetings and PLCs to create effective instructional materials for the classroom and determine how students will learn from them. Effective partnering among teachers, librarians, and school leadership supports the implementation of intentional integrated STEM curricula into a school.

While the STEM specialist initially drove a lot of the innovations and lesson ideas, as teachers gained STEM content knowledge, they contributed more to the instructional design of the lessons during planning time. For example, a second-grade teacher noted how the STEM specialist now guides them during EDP planning to take initiative and ask them how they will "make it [EDP lesson or STEM concept] even more of a challenge." According to the interviewees, this planning was specific to the engineering lesson and was in addition to team planning and PLCs. During this time, teachers completed three instrumental tasks: 1) collaborated to find a key concept that could be applied to solve a real-world problem (not just STEM) and draw arrows connecting the cross-curricular concepts, 2), select a topic within the area with the most connections, 3) identify the anchor discipline for the STEM Block, and 4) create daily EDP plans for students in engineering laboratory during the STEM Block unit. In the survey, a third-grade teacher explained this process when she responded, "As a team we look at all curriculum and find the connections. It can be as simple as connecting writing and reading procedures to conducting an experiment in the lab or engineering a product." Figure 1 is a sample artifact from a second-grade planning meeting showing how educators worked together to create meaningful STEM experiences for the students at GES.

Figure 1
Example of Collaboration During Second-Grade Teacher Planning



Science	Language Arts	Math	Social Studies	Technology	Engineering
Characteristic of Scientists a. Tools they use b. Safety Scientists Communicate – GEMS Group Solutions Inquiry Investigation – Observation and Inferences - Mexican Jumping Beans Scientists conduct experiments using structured steps Best Raincoat material	Launching Reading Workshop Readers Build Good Habits -Read aloud Writing – Quick Write week and Writer's Notebook Personal Narrative	Addition and Subtraction to 99 Addition and subtraction with money Perimeter of a square Learn the number line Rounding Estimation Place value	Where in the World? Using a Compass Rose United States Texas – State Mexico – Country Geography Learn states and directions	Students watch Safety and Tools PowerPoint	

Teachers collaborative work focused on promoting student interest and engagement in STEM. Working jointly to address concerns and solve problems led to innovative ideas that often-deepened student STEM engagement. A second-grade teacher felt that, "Either at the makerspace in the library, the engineering lab, or our STEM bins" was where student engagement increased. Seeing the need to integrate STEM into the content specific classrooms to provide consistent practice and engagement, the librarian collaborated with teachers and created mobile makerspace carts for them to check out. "I wanted teachers to become comfortable with that material without me standing over them or anyone else seeing what they are doing", she recollected. A second-grade teacher recalled how the librarian encouraged their input to personalize the Makerspaces for students. She shared, "She's got a rotating makerspace cart that we're gonna share… but I think she's changing it a little bit maybe for us. 'Cause she called us in personally to say, "What do you all want to see in your makerspace cart?" The librarian collaborated often with teachers to increase students' STEM knowledge and engagement.

Another example of teacher collaboration led to mobile makerspaces and STEM bins providing seamless integration of STEM curriculum throughout the school which provided a natural aspect in which teachers and students build capacity, confidence, and interest in STEM concepts and careers. A second-grade teacher recalled that the idea of using STEM bins in the classroom was developed during one of their PLC meetings. According to the second-grade teachers in the focus group, the STEM bins had different STEM activities that connected STEM to literacy, reading, and writing through the utilization of fiction and nonfiction stories and teachers would rotate them every week. The second-grade teacher elaborated and said, "So if they [the students] had that constant practice on a weekly basis [with STEM bins], of engineering and designing and working cooperatively with whoever's in their group, when they get to the engineering lab, it's just a seamless process." As a result of this instructional innovation, teachers believed students' interest and engagement during the classroom and EDP increased because of their interactions with the STEM bins prior to participating in the engineering STEM block week. "They [the students] become different kinds of learners when they've been exposed to that [STEM concepts] in lots of different places," shared another second-grade teacher.

Professional development proved to be a vital component to the success of fostering the STEM-driven school culture. In particular, the nurturing support of school leadership strengthened and expanded educators' perspectives of STEM instruction and vision of a STEM school. As the principal delved deeper into developing a sound, sustainable initiative with STEM curricula, he shared that he knew quality training and educator support for teachers would be vital to their success. He believed that teachers would have to receive professional development for content and pedagogical skills in their core content areas and in STEM content to develop their abilities to integrate STEM curricula effectively. When asked about the role that professional development played in helping teachers develop their STEM content and pedagogical practices, the principal replied:

> I think the biggest contributor in some ways was simply go attending [attend] conferences because we didn't have a lot of models within the district, for instance, or on our campus about what STEM is or how it functions or how it could function in a school building. So, we really had to go out and do a lot of research by attending conferences.

The STEM specialist commended the principal's awareness of teachers' needs. "I think one of the biggest a-ha's that our principal had was the need for effective staff development," she remembered about how the principal chose to invest in teachers going to national and state conferences.

Teachers were also supported to attend conferences to gather ideas for furthering the integration of STEM curricula, thus reinforcing a STEM-driven mindset and shared vision. As a result, teachers began creating new STEM experiences for students and modified the ones they already had in place. One second-grade teacher shared what she perceived as vital about attending conferences. She recalled:

> It [attending conferences] changes your mindset and even looking at the science curriculum that we already have, one of the activities in our science curriculum, we ended up adapting and changing to a STEM lab just because if you're already thinking that mindset of how can I change, just take a lesson and turn it into a project-based lesson or STEM activity, you can find it everywhere if you're in that mindset.

Thus, she perceived that attending conferences provided teachers with a platform where they felt comfortable modifying science lessons to meet the needs of their STEM students. Having the ability and mindset empowered the teachers, which strengthened their confidence in teaching STEM curricula and development as experts in integrated STEM instruction. As teachers began to develop their STEM expertise, they began presenting at local and national STEM conferences. A fifth-grade mathematics teacher recalled how she began presenting at national conferences: "At this time, I began presenting our own Engineering lessons and campus program framework at these national conferences." It appeared that several teachers took pride in sharing their experiences and knowledge with other educators across the nation.

5. Discussion

5.1. STEM-driven School Culture

One of the most important findings of this study is that a shared STEM-driven mindset grounded school leaders, teachers, and students in a common vision and expectation for learning, thus forming what is called in this study a *STEM-driven school culture*. Educator comments revealed that the multifaceted, common culture to be a key component of their perceptions about Gemini's success as a STEM school. Schein and Schein (2017) posited that culture is representative of different organizational structures that impact change, adopted norms and values, and assumptions regarding culture as a product of leadership.

The findings of this study revealed that K-5 STEM educators perceived having a shared vision is foundational to creating a STEM-driven school culture that values and promotes teacher collaboration and professional development. Identifying key components of a successful STEM elementary school are beneficial to school leaders and teachers interested in transitioning to a

STEM school. Educators' perceptions are important because they shed light on school leaders' roles in providing a clear vision, creating teacher buy-in, and supporting teachers' growth through professional development and collaboration opportunities. Like other researchers we argue that school administrators and teacher leaders are instrumental for propelling initiatives and creating a STEM culture that is conducive to student learning (Peters-Burton et al, 2019; Rose et al., 2019; Wieselmann et al., 2021). Creating buy-in from staff members is essential in the implementation and sustainability of STEM schools. As seen in this study, the principal took teachers' thoughts and opinions regarding STEM components and curricula into careful consideration during individual, team, and faculty discussions. This process begins with school leaders who have a clear vision that provides a collaborative environment that empowers all staff members to continue learning and be open to innovation (Peters-Burton et al., 2019). Principal's leadership and actions reflect can often reflect the value for teachers as partners in designing and building STEM schools. Including teachers in key committees such as the exploratory committee provides an opportunity for school administrators to build trust among teacher leaders. Clear visions coupled with rational trust can create an environment where the principal can "walk the walk" with teachers and students as they embark on transitioning into a STEM school (Falloon et al., 2021).

Another significant layer to school culture that this study uncovered was the need to foster a shared vision of creating a safe, inclusive STEM elementary school that encouraged all learners to make mistakes, learn, and redesign that creates a culture that embraces failure. School cultures are key components of STEM schools and could develop through purposeful efforts, routines, and school traditions (Lynch et al., 2018). Over time, a STEM-driven school culture can develop that encourages teachers and students to take professional and academic risks. Teachers' STEM content and pedagogical knowledge, practice, and confidence can grow by trying new STEM methods and practices and reflecting upon what did not work (failure). Accepting failure as an integral part to learning encouraged teachers and students to be risktakers, according to the educators at GES. This risk-taking can provide innovative changes to classroom instruction. More importantly, STEM learning environments encourage students learn to embrace failure as part of the learning process, thus bolstering their confidence and willingness to take risks. Risk-taking can be difficult, so positive learning environments can be safe spaces for students to make and learn from mistakes. A school culture that supports and encourages the mindset of making mistakes, learning, and redesigning where students practice STEM concepts on a continual basis helps foster a STEM-driven school culture. Similarly, El Nagdi et al. (2018) support risk-taking characteristics in teachers because they enhance students' STEM learning opportunities. As a result, a STEM-driven growth mindset can continue to be cultivated and become a strong element throughout STEM schools.

5.2. Collaboration and Professional Development

In addition to a STEM-driven school culture, this study indicated that key factors in the implementation, success, and sustainability of STEM schools included teacher collaboration and STEM-focused professional development. With the shift from managers to instructional leaders, school leaders can not only impact the implementation of STEM concepts into a school (Watson et al., 2022) but provide collaborative experiences that help sustain integrated STEM programs (El Nagdi et al., 2018; Fairweather, 2008). Providing teachers with access to STEM curriculum and instruction experts such as a STEM specialist in class and planning time can increase teachers' STEM capacity. Therefore, hiring a STEM coordinator for individual schools could provide teachers with the professional learning experiences needed to improve their STEM professional practice (Wieselmann et al., 2021). Furthermore, Johnson et el. (2016) indicated that collaboration during team planning and working with STEM experts help develop school climates. Continual practice of team planning and brainstorming innovative ideas strengthens teachers' understanding of the school vision and implementation of integrated STEM curricula. Watson et al. (2022) believed that collaboration in PLCs nurtures teachers' STEM awareness and capacity which affords them ways to increase STEM interactions for students. Furthermore, school leaders should schedule intentional teacher collaboration opportunities such as team planning and half-day planning time. Collaborative experiences such as these are essential to integrating STEM successfully in schools (Fairweather, 2008) which can provide sustainability over the years to integrating STEM and help foster a STEM mindset throughout the school for all stakeholders.

Promoting teachers' collaboration and innovation with curriculum and instruction design that allows for integration of other content areas such as reading (e.g., STEM bins with connections to literacy) provides students with opportunities to gain a greater knowledge and understanding of STEM concepts. Making connections with STEM and literacy begins to build a foundation that can capture and expand students' interest in STEM (Tanenbaum, 2016). Expanding collaborative efforts to include school librarians can provide a comprehensive approach to integrating STEM concepts. Finding innovative ways to increase students' STEM experiences throughout the school day can enhance their STEM learning (Peters-Burton et al., 2019). Additional opportunities to engage and tinker with STEM concepts using Makerspaces in the library, classroom, and at home expands students' ability to apply learned STEM knowledge in multiple ways. These additional experiences for students can increase their confidence and positively impact students' attitudes towards STEM careers (Wang, 2013). These collaborative actions between teachers and the librarian could not only support school's vision but also help create and sustain a STEM-driven school culture that expanded beyond the school's walls.

This research suggests that having school leaders, such as a STEM specialist to develop teachers' STEM content knowledge and pedagogical skills, is a key element to a STEM school's success. This can be done through a series of in-service professional development sessions prior to the beginning of the school year and throughout the school year. Purposeful planning of curriculum and instruction and providing professional development helps schools with the successful implementation of integrated STEM (Rose et al., 2019). STEM professional development is a tool that informs, extends, and sustains educators' pedagogical content knowledge and perception of a STEM-driven curriculum and school approach. Equipping educators with real-world STEM applications is an important foundation of STEM learning (Margot & Kettler, 2019). These experiences build teachers' capacity in STEM content and STEM application; thus, allowing seamless integration STEM concepts throughout classroom instruction and daily practice.

This study also indicated the teachers' professional learning extended beyond the school and needed to include STEM conferences that developed educators' STEM professional practice. School leaders are instrumental in the ability to provide teachers with access to educator supports that provide acquisition of STEM content and pedagogical skills. This study revealed that conference presentation may be presented as STEM but might not meet the needs developing STEM teachers who feel STEM should be fully integrated. The study by English (2016) supports the idea of utilizing a fully integrate approach to STEM concepts because it builds students' curiosity and understanding of connections throughout STEM. Attending national STEM conferences increases networking with other STEM educators who also may believe STEM should be fully integrative in nature. Hence, expanding teachers' STEM capacity and ability to integrate concepts and provide real-world STEM connections (Honey et al., 2014; Subramanian & Clark, 2016). Both elements of collaboration and professional development created an environment with a continuous dialog centered on STEM schools, curriculum, and learning, thus supporting shared visions, and contributing to a growing STEM-driven culture.

6. Limitations

Since this is a case study, the findings from this study may not be generalized to all STEM elementary schools. The reader should be alert to the possible biases of the participants since they are from a STEM elementary school. This school was purposely selected due to the implementation of integrated STEM curricula as we needed to identify key components of the school's success. Participants might be biased about their school's success and want to showcase their school as successful. Thus, the results may be biased towards what key components are successful.

7. Conclusion

Given the dearth of research on STEM educators' perceptions of successful STEM-focused elementary schools, this study addresses a gap in literature and provides insight to researchers and school districts planning on developing STEM-focused elementary schools can draw on. The culmination of vision, risk-taking, professional development, and instructional design has provided an additional layer to a STEM-driven school culture that provides students with the opportunities to build the interest in STEM through engaging them in the classroom, engineering laboratory, library, and at home. Building teacher capacity impacts their effectiveness in the classroom, thus influencing student experiences and perceptions of STEM. School leadership decisions and actions can empower educators and lead transformation. Realizing that students needed more opportunities to expand their STEM mindset, the librarian created a makerspace in the library, mobile makerspaces for the classroom, and kits for students to take home so they had more time to tinker, play, and explore topics that interested them. These experiences provided students with an increased opportunity to increase their 21st century skills while boosting their confidence and STEM capacity.

Integrated STEM approaches are used and thought to prepare students to be solution-oriented and help possibly meet the challenges facing the deficit in the STEM workforce. Two themes, (a) STEM-driven school culture and (b) collaboration and professional development, were identified as instrumental in identifying key components of a successful STEM elementary school. The principal's initial vision of finding a solution to the attendance problem due to rezoning paved the way to develop a STEM initiative which fostered a paradigm shift in teachers' and students' mindset, understanding, and application of STEM education. Unpacking a STEM-driven school culture determined that it is multifaceted, includes subthemes of educator supports and interest and engagement in STEM, and provides a safe environment that embraces failure as a natural part of learning and affords educators' and students' STEM mindset to be in a constant state of evolution. The findings are intended to inform educators who want to implement integrated STEM curricula and opportunities into their school.

8. Recommendations

Recommendations for future studies includes additional research to better understand components of a STEM-driven school culture in K-12 STEM schools. This would help refine the definition and better understand how it applies to different STEM schools. Research should also examine the impact of utilizing EDP as a main focus of STEM integration and its relationship, if any, to developing a STEM-driven school culture. In addition, future research should include the understanding and application of the impact of embracing a STEM-driven school culture in traditional K-12 schools which could expose all students to EDP that promotes risk-taking and productive failure as its vision and mindset. Furthermore, future research could examine the leadership approach to distribute decision-making among other school leaders and faculty.

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References

Beede, D. N., Julian, T. A., Landon, D., McKittrick, G., Khan, B, & Doms, M. E. (2011). *Women in STEM: A gender gap to innovation*. U.S. Department of Commerce. ESA Issue Brief #04-11. Retrieved from http://www.esa.doc.gov/sites/default/files/womeninstemagaptoinnovation8311.pdf

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education*, *97*(3), 369–387. https://doi.org/10.1002/j.2168-9830.2008.tb00985.x

Bureau of Labor Statistics (BLS). (2020). Employment in STEM occupations. Retrieved from https://www.bls.gov/emp/tables/stem-employment.htm

Cohen, J., McCabe, L., Michelli, N., & Pickeral, T. (2009). School climate: Research, policy, practice and teacher education. T*eachers College Record*, *111*(1), 180-213. https://doi.org/10.1177/016146810911100108

Creswell, J. (2007). *Qualitative inquiry and research design* (2nd ed). Sage Publications.

Cunningham, B. C., Hoyer, K. M., & Sparks, D. (2015). *Gender differences in science, technology, engineering, and mathematics (STEM) interest, credits earned, and NAEP performance in the 12th grade. Stats in brief.* NCES 2015-075. U.S. Department of Education National Center for Education Statistics.

El Nagdi, M., Leammukda, F., & Roehrig, G. (2018). Developing identities of STEM teachers at emerging STEM schools. *International Journal of STEM Education*, *5*(1), 1-13. https://doi.org/10.1186/s40594-018-0136-1

English, L. D. (2016). STEM education K-12: perspectives on integration. *International Journal of STEM Education*, *3*(1), A3. https://doi.org/10.1186/s40594-016-0036-1

Erdogan, N., & Stuessy, C. L. (2015). Modeling successful STEM high schools in the United States: An ecology framework. *International Journal of Education in Mathematics, Science and Technology, 3*(1), 77-92.

Erickson, F. (1987). Conceptions of school culture: An overview. *Educational Administration Quarterly*, *23*(4), 11-24.

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

Falloon, G., Stevenson, M., Beswick, K., Fraser, S., & Geiger, V. (2021). Building STEM in Schools: An Australian cross-case analysis. *Educational Technology & Society, 24*(4), 110-122.

Fullan, M. (2003). *The moral imperative of school leadership.* Corwin.

Fullan, M. (2007). *The new meaning of educational change.* Teachers College Press.

Granovskiy, B. (2018). *Science, Technology, Engineering, and Mathematics (STEM) Education: An Overview.* CRS Report R45223, Congressional Research Service.

Haddad, W. D., & Draxler, A. (2002). The dynamics of technologies for education. In Wadi, D., Haddad & Alexandra Draxler (Eds.), *Technologies for Education Potentials, Parameters, and Prospects* (pp. 2–17). UNESCO.

Hammack, R., & Ivey, T. (2017). Examining elementary teachers' engineering self-efficacy and engineering teacher efficacy. *School Science and Mathematics, 117*(1–2), 52–62. https://doi.org/10.1111/ssm.12205

Hammack, R., & Ivey, T. (2019). Elementary teachers' perceptions of K-5 engineering education and perceived barriers to implementation. *Journal of Engineering Education*, *108*(4), 503-522. https://doi.org/10.1002/jee.20289

Hierck, T. & Peterson, K. (2018). Focusing on the 19 behaviors most essential to a positive school culture. *ASCD Express, 13*(14), 1-4.

Holmlund, Lesseig, K., & Slavit, D. (2018). Making sense of "STEM education" in K-12 contexts. *International Journal of STEM Education*, *5*(1), 1–18. https://doi.org/10.1186/s40594-018-0127-2

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research.* National Academies Press.

Jackson, A., Godwin, A., Bartholomew, S., & Mentzer, N. (2021). Learning from failure: A systematized review. *International Journal of Technology and Design Education*, 1-21. https://doi.org/10.1007/s10798-021-09661-x

Johnson, C., Peters-Burton, E., & Moore, T. (2016). *STEM road map*. Routledge.

Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *Journal of the Learning Sciences, 21*(1), 45–83. https://doi.org/10.1080/10508406.2011.591717

Lesseig, K., Firestone, J., Morrison, J., Slavit, D., & Holmlund, T. (2019). An analysis of cultural influences on STEM schools: Similarities and differences across K-12 contexts. *International Journal of Science and Mathematics Education*, *17*(3), 449-466. https://doi.org/10.1007/s10763-017-9875-6

Lichtman, M. (2010). *Qualitative research in education a user's guide*. Sage.
Lynch, S. J., Burton, E. P., Behrend, T., House, A., Ford, M., Spillane, N., Matray, S., Han, E., & Means, B. (2018). Understanding inclusive STEM high schools as opportunity structures for underrepresented students: Critical components. *Journal of Research in Science Teaching*, *55*(5), 712–748. https://doi.org/10.1002/tea.21437
Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: a systematic literature review. *International Journal of STEM Education, 6*(1), 1-16. https://doi.org/10.1186/s40594-018-0151-2
McKay, S. R., Millay, L., Allison, E., Byerssmall, E., Wittmann, M. C., Flores, M., ... & Smith, M. K. (2018). Investing in teachers' leadership capacity: A model from STEM education. *Maine Policy Review*, *27*(1), 54-63.
Miller, R. K. (2017). Building on Math and Science: The New Essential Skills for the 21st-Century Engineer: Solving the problems of the 21st century will require that engineers have a new set of skills and mindsets. *Research-Technology Management, 60(*1), 53-56. https://doi.org/10.1080/08956308.2017.1255058
National Science Board. (2007). *A national action plan for addressing the critical needs of the U.S. science, technology, engineering, and mathematics education system.* National Science Foundation.
Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049-1079. https://doi.org/10.1080/0950069032000032199
Partnership for 21st Century Learning. (2009). *P21 Framework definitions.* Retrieved from https://files.eric.ed.gov/fulltext/ED519462.pdf
Peters-Burton, E. E., House, A., Peters, V., & Remold, J. (2019). Understanding STEM-focused elementary schools: Case study of Walter Bracken STEAM Academy. *School Science and Mathematics*, *119*(8), 446-456. https://doi.org/10.1111/ssm.12372
Peters-Burton, E., Lynch, S., Behrend, T., & Means, B. (2014). Inclusive STEM high schools: 10 critical components. *Theory Into Practice*, *53*, 64– 71. https://doi.org/10.1080/00405841.2014.862125
Peterson, K. D., & Deal, T. E. (2011). *The shaping school culture fieldbook*. John Wiley & Sons.
President's Council of Advisors on Science and Technology (2012). *Report to the president engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics*. Retrieved from https://www.whitehouse.gov/sites/default/ files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf
Rigby, J. G., Larbi-Cherif, A., Rosenquist, B. A., Sharpe, C. J., Cobb, P., & Smith, T. (2017). Administrator observation and feedback: Does it lead toward improvement in inquiry-oriented math instruction?. *Educational Administration Quarterly*, *53*(3), 475-516. https://doi.org/10.1177/0013161X16687006
Rose, M. A., Geesa, R. L., & Stith, K. (2019). STEM leader excellence: A modified delphi study of critical skills, competencies, and qualities. *Journal of Technology Education*, *31*(1), 42-62.
Rozek, C. S., Svoboda, R. C., Harackiewicz, J. M., Hulleman, C. S., & Hyde, J. S. (2017). Utility-value intervention with parents increases students' STEM preparation and career pursuit. *Proceedings of the National Academy of Sciences*, *114*(5), 909-914. https://doi.org/10.1073/pnas.1607386114
Sanders, M. (2008). STEM, STEM education, STEMmania. *Technology Teacher, 68*(4), 20-26.
Sargent Jr, J. F. (2017). *The US science and engineering workforce: Recent, current, and projected employment, wages, and unemployment*. Retrieved from https://sgp.fas.org/crs/misc/R43061.pdf
Schein, E. H. & Schein, P. A. (2017). *Organizational culture and leadership* (5th ed.). Wiley.
Schneider, K. K., Bahr, D., Burkett, S., Lusth, J. C., Pressley, S., & VanBennekom, N. (2016). Jump starting research: Preresearch STEM programs. *Journal of College Science Teaching, 45*(5), 13-19.
Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education*, *4*(1), 1-16. https://doi.org/10.1186/s40594-017-0068-1
Smith, K. L., Rayfield, J., & McKim, B. R. (2015). Effective practices in STEM integration: Describing teacher perceptions and instructional method use. *Journal of Agricultural Education, 56*(4), 183-203. https://www.doi.org/10.5032/jae.2015.04183
Stolp, S. W. (1994). *Leadership for school culture. Eric Digest 91.* Retrieved from https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/3312/digest091.pdf
Subramanian, R., & Clark, S. (2016). *The partnership of University, Industry and K-12 Schools to improve awareness of STEM fields*. Retrieved from https://www.hofstra.edu/pdf/academics/colleges/seas/asee-fall-2016/asee-midatlantic-f2016-subramanian.pdf

Tanenbaum, C. (2016). *STEM 2026: A vision for innovation in STEM education*. Retrieved from https://innovation.ed.gov/files/2016/09/AIR-STEM2026_Report_2016.pdf

Tsupros, N., Kohler, R., & Hallinen, J. (2009). *STEM education: A project to identify the missing components*. Intermediate Unit 1 and Carnegie Mellon.

Wang, X. (2013). Why students choose STEM majors: Motivation, high school learning, and postsecondary context of support. *American Educational Research Journal*, *50*(5), 1081-1121. https://doi.org/10.3102/0002831213488622

Watson, S., Williams-Duncan, O. M., & Peters, M. L. (2022). School administrators' awareness of parental STEM knowledge, strategies to promote STEM knowledge, and student STEM preparation. *Research in Science & Technological Education, 40*(1), 1-20. https://doi.org/10.1080/02635143.2020.1774747

Wieselmann, J. R., Roehrig, G. H., Ring-Whalen, E. A., & Meagher, T. (2021). Becoming a STEM-focused school district: Administrators' roles and experiences. *Education Sciences*, *11*, 805. https://doi.org/10.3390/educsci11120805

Wisnall, R., Stiefel, L., Schwartz, A., & Boccardo, J. (2014). Does attending a STEM high school improve student performance. *Evidence from New York City*, *40*, 93-105.

Appendix. Survey questions asked participants to elaborate and included:

1) If you write/develop lesson plans with other teachers, how does planning with your team impact STEM lessons in your classroom or laboratory?
2) How do you implement STEM education in your classroom?
3) What are key components you feel makes your STEM school successful?
4) What types of STEM education professional development training have you received?

Focus group questions included:

1. At this school, how is STEM education approached?
2. What do you think are key components of a successful STEM school?
3. Which of the following components do you feel are vital to a successful STEM school?
    a. Tangible STEM components, makerspace (regular and portable), engineering lab, use of technology, robotics
    b. Guest speakers, field trips, donations
    c. Professional development
    d. Other