Teachers as Designers: Case Study of Early Adopters Integrating STEM Systemically into their K-12 School

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Abstract

This case study explored the efforts of a group of early adopter teachers at a private K–12 school in the Mid-Atlantic region who initiated a grassroots, teacher-led effort to integrate STEM systemically across their school. While most STEM school reform is typically driven top-down by district or administrative mandates, this study documents how five experienced teachers collaboratively envisioned and designed school-wide STEM programming grounded in student-centered learning and self-regulated learning (SRL). Guided by inventories of critical components from effective STEM schools and a conceptual framework emphasizing SRL as a key habit of mind, the teachers engaged in professional development, examined school-wide needs, and implemented pilot initiatives within their own classrooms. Data sources included interviews, field notes, classroom observations, and validated STEM component inventories. Findings reveal that while teachers across the school expressed confidence in implementing STEM within their individual classrooms, systemic challenges such as limited community partnerships and cross-disciplinary coordination hindered broader integration. The early adopters identified student agency and SRL as central to effective STEM learning and developed tools and strategies to foster these skills. Their actions illustrate a promising pathway for teacher-led STEM reform and offer practical insights for schools seeking to expand equitable and authentic STEM experiences.

STEM schools in the US have been in place since the late 1900s, although these early STEM schools were small in number and had competitive admission standards, allowing only elite students to attend (Kaser, 2006). More recently, there has been a marked trend worldwide to broaden rigorous STEM offerings to all students. This movement has produced more STEM schools, often fueled by dwindling standings in global comparative exams (Bybee, 2013). The purpose of education offered at a specialized STEM school, whether it is selective or inclusive, generally takes two forms: (a) attract students to STEM subjects in secondary and higher education, with the aim of encouraging them to move to STEM professions, and (b) promote STEM literacy among all students (Johnson et al., 2021). Roehrig, Moore, Wang, & Park (2012) argued that our daily challenges are "multidisciplinary, and many require integration of multiple STEM concepts to solve them" (p. 31). Many of these STEM-focused schools are created because public school districts want to draw students to a magnet school or because the community requests the school district to create more STEM offerings at schools (Peters-Burton et al., 2020). This study, however, documents another situation – when teachers want to build more school-wide integrated STEM offerings at their own schools. This study is unique because, in most cases, building a STEM school is a top-down endeavor. In this context, a small group of teachers are the lead designers in increasing STEM opportunities for their students, informed by the needs of the whole school. This paper shares a case study of a group of “early adopter” teachers as they collaborate, envision, and design new STEM programming in a private K-12 school setting. We aim to highlight lessons learned from this engagement toward providing a tangible pathway for improving their integrated STEM offerings.

Conceptual Framework

This work builds from the findings of two research teams that reverse-engineered critical components from successful STEM-focused elementary schools (House et al., 2020) and inclusive STEM high schools (Lynch et al., 2018). Across eight years, the teams visited successful elementary and secondary schools with a STEM focus and more diverse student bodies than their neighboring schools. The summary of the work from both teams resulted in two self-assessment-type inventories of the critical components that can act as a tool to find leverage points from which to enhance STEM offerings. One inventory focused on critical components at the elementary school level, and the other focused on the secondary level. The components in the inventories are found in Table 1 (elementary level) and Table 2 (secondary level). The complete inventories with definitions and questions related to each component can be found in Appendix 1 (elementary level) and Appendix 2 (secondary level).

Table 1

Critical Components of STEM-Focused Elementary Schools in Inventory

School Purpose and Process

1. Inclusive STEM mission
2. Climate of intellectual safety
3. Distributed leadership
4. Evidence-based improvement

Community Relationships

5. Community engagement in STEM
6. Supporting STEM partnerships

School Staff

7. Teacher develop and refine core curricula
8. Teachers as STEM educators
9. Dedicated STEM staff

School STEM Resources

10. Technology used to support STEM
11. School physical setting

STEM Program

12. Interdisciplinary STEM lessons
13. Participation in STEM practices
14. Widespread use of design cycle
15. 21st century skills used for STEM learning
16. High level STEM content
17. Student ownership of learning

Table 2

Critical Components in Secondary level STEM School Inventory

CC1. College-Prep, STEM Focused Curriculum for All

CC2. Reform Instructional Strategies and Project-Based Learning

CC3. Integrated, Innovative Technology Use

CC4. STEM-rich, Informal Experiences

CC5. Connections with Business, Industry, and the World of Work

CC6. College Level Coursework

CC7. Well-Prepared STEM Teachers and Professionalized Teaching Staff

CC8. Inclusive STEM Mission

CC9. Flexible and Autonomous Administration

CC10. Supports for Underrepresented Students

CC11. Data Driven Decision Making for Continuous Improvement

CC12. Innovative and Responsive Leadership

CC13. Positive School Community and Culture of High Expectations for All

CC14. Agency and Choice

Some critical components focus on features external to a teacher's influence, such as administrative leadership orientation and school purpose. However, many of the critical components found in these highly functioning STEM schools feature students' personal ownership of learning as a core focus, which teachers can enact. For example, elementary STEM-focused schools' critical components feature a School Culture of Intellectual Safety, and Interpersonal Trust, and Student Responsibility for Learning (House et al., 2020). The secondary STEM school critical components feature student-centered learning, such as in Reform Instructional Strategies, Positive School Community and Culture of High Expectations for All, and Agency and Choice (Lynch et al., 2018). Schools that want to improve their STEM offerings can use this work on critical components to find what they already do well and what they want to improve. Using elementary and secondary Critical Components, this study focuses on those components that allow for student responsibility for learning, namely, self-regulated learning.

Self-Regulated Learning (SRL)

Individuals who practice SRL exhibit agency throughout their learning process as they manage certain behavioral, environmental, and cognitive aspects of their learning to achieve pre-established learning goals (Schunk & Usher, 2013). There is a great deal of evidence across content areas that demonstrates the usefulness of supporting student SRL in academic areas such as mathematics (Chen et al., 2018), English language arts (Palinscar et al., 2018), social studies (Schunk et al., 2018), and science (Cleary et al., 2018; Peters, 2012).

SRL consists of three distinct phases that learners engage in *as they prepare to learn* (forethought phase), *while they learn* (performance phase), and *after they learn* (self-reflection phase). During the forethought phase, learners prepare to learn by setting specific goals and engaging in thoughtful planning (Zimmerman, 2000). During the performance phase, learners enact the plans they developed in the forethought phase while actively monitoring their progress (Cleary et al., 2017). In the self-reflection phase, learners analyze the feedback obtained during the performance phase and consider how it can support future performance improvements (Cleary et al., 2017). Zimmerman (2002) offered a four-stage coaching strategy that has shown merit in the science classroom (Greene et al., 2018; Peters & Kitsantas, 2010; Peters-Burton & Burton, 2020). This coaching strategy can be adopted by teachers to support student SRL.

Situated in the conceptual framework of STEM critical components and SRL, this study examined the decisions a core group of teachers made as they began work to improve their school's STEM offerings. They aimed to try out their ideas in their own classrooms in the first year, collecting data and evaluating the evidence of success. They intended to scale up the successful ideas to the whole school in the following year. Our work was driven by the research question: What choices do a group of early adopter teachers make to systemically enhance STEM offerings in a private K-12 school setting? We hope that the findings of this study may be used in other contexts for schools wanting to improve their STEM programs and offerings.

Method

Setting and Participants

This study occurred in the context of a private PK-12 school located in the mid-Atlantic region. The school serves 388 students PK-12 and has a total of 52 teachers. A total of five early adopter teachers, the focus of our study, took part in a professional development training over the summer. The teachers had an average of 12.8 years of experience, and many had decades of experience in STEM fields outside of teaching. The early adopter team consisted of a 4th and 7th-grade mathematics teacher, a 6th and 7th-grade science teacher and elementary STEM coordinator, a 7th-grade social studies teacher, a 9th and 10th-grade biology teacher, and a 12th-grade environmental science and calculus teacher.

Research Design

To answer our research question, we employed a case study design with the goal of better exploring the teachers' diverse perceptions and understanding their experiences in context (Stake, 1995). The case was defined as the group of early adopter teachers, teachers who are proactive in seeking out new pedagogical approaches, and was bounded by the time frame of this study, activities related to the professional development training, and the context of the school setting in which the study takes place.

Procedure

The head administrator for the school reached out to the first author seeking support in enhancing her school's integrated STEM offerings. After this initial conversation, all three authors met with the head administrator and discussed the current status and goals of the school related to integrated STEM. At this time, the administrator identified a potential list of early adopter teachers who would possibly be interested in participating in a summer professional development and planning opportunity. Once all necessary documents were obtained, teachers were notified of the opportunity to participate in the STEM components inventory and to take part in the early adopters' professional learning and planning meetings. A total of five early adopters volunteered, and a three-day professional development training and planning session occurred at the beginning of the summer. Over those days, the five teachers met with the three researchers and engaged in professional learning about integrated STEM and SRL and science and engineering practices, as well as discussed and planned their goals and implementation strategies. During this time, the three researchers also took detailed, open-ended field notes.

Data Sources

Data sources include (a) multiple interviews with the administrator of the school, (b) field notes from observations of the physical school setting, including building layout, laboratories, and areas designated as a maker space, (c) inventory results from entire school from the Elementary STEM-Focused Schools Critical Components Inventory (House et al., 2020) and the Secondary STEM Schools Critical ComponentsInventory (Peters-Burton et al., 2020a), and (d) researcher field notes from the professional development training and teacher discussions with a small group of early adopter teachers. Individual interviews about choices and implementation of classroom materials with each of the five early adopters were conducted in the Fall.

Administrator Interview. Prior to visiting the school, the lead author conducted an hour-long semi-structured interview with the head administrator via Zoom. The interview focused on the school's strengths, weaknesses, opportunities, and goals related to integrated STEM.

Observations of the School Setting. All three authors traveled to the school for a two-hour tour and meeting with the lead administrator to discuss overarching school goals and potential opportunities. The school tour included both elementary and secondary buildings, STEM and science classrooms, and outdoor and communal spaces. As the tour occurred during a school day, most students were actively engaged in classroom activities, and teachers were busy instructing.

Inventories. Two validated inventories were administered to the teachers and administrator. The elementary-level teachers received the STEM-Focused Elementary School Components Ratings Inventory (House et al., 2020), and the secondary teachers received the Secondary STEM Schools Critical Components Inventory (Peters-Burton et al., 2020a).

Both of the inventories are available in the Appendices or from the corresponding author (first author). The administrator of the school received both inventories. All 54 teachers and the administrator were contacted via email and asked to complete either the elementary or secondary STEM critical components inventory over a two-week period. Thirty inventories were returned with all questions answered, resulting in a 56% response rate.

Field Notes from the PL session. The inventory results were presented and discussed at the beginning of a three-day professional development PD training for the five early adopters. The purpose of the PD was to support these early adopters in identifying and defining their goals with input from the broader school context. Throughout the three-day professional learning and planning sessions, field notes were collected by all three authors. These notes were focused on their description and observation of the conversations, questions, concerns, and ideas the teachers had. As the authors were present to both provide support and training and to observe and gather data, the role of all three authors would be best described as 'Observer-as-participant' (Gold, 1958). The field notes were taken from the time the meeting started each day until it ended, and the authors edited the notes as soon as possible to ensure that their observations were documented accurately.

Data Analysis

Interviews and field notes were coded independently by each of the authors, who then met to discuss their codes. Thematic analysis was employed to organize and describe the data in rich detail, noting relationships, similarities, and differences in the data (Braun & Clark, 2006). The goal of thematic analysis is to develop a theme or themes that reflect the important ideas or concepts that emerged from the interaction of the researchers and the data. We followed the steps for thematic analysis laid out by Braun and Clark (2006) and familiarized ourselves with the data by reading and re-reading all data sources and noting initial ideas individually. We then iteratively worked to generate initial codes, systematically coding notable features across the entire data set. The codes that described the notable features included many of the teacher- and classroom-related critical components from the inventories and ideas about student learning. For this, we used emergent and iterative coding until we reached data saturation. Next, we searched for potential themes represented in the data, again iteratively reading and re-reading until we felt we met consensus. Finally, we reviewed our themes, refining and ultimately defining them. As all three researchers were actively involved in observing, taking field notes, and communicating, we engaged in investigator triangulation to increase validity and reduce bias (Denzin, 2009). Descriptive statistics were calculated to communicate the nature of the responses for each of the inventories to the early adopters. The data were reviewed for completeness and cleaned to remove any non-relevant fields (e.g., demographic information or incomplete responses), and only Likert-scale items tied to the Critical Components Inventory were included in the analysis. Each item was mapped to its corresponding STEM component using a predefined key provided alongside the instrument. This mapping allowed us to group individual item responses under broader categories, such as Student Ownership of Learning or Community Engagement in STEM. Next, for each item, we calculated the number of responses in each of the four Likert categories: *Strongly Agree, Agree, Disagree,* and *Strongly Disagree*. To enable comparison across components with varying numbers of responses, we then normalized the data. Specifically, we calculated the percentage of responses in each category based on the total number of responses per item. Not only did these statistics provide valuable insights into the overall school context, but they were also a source of discussion during the professional development days.

Findings

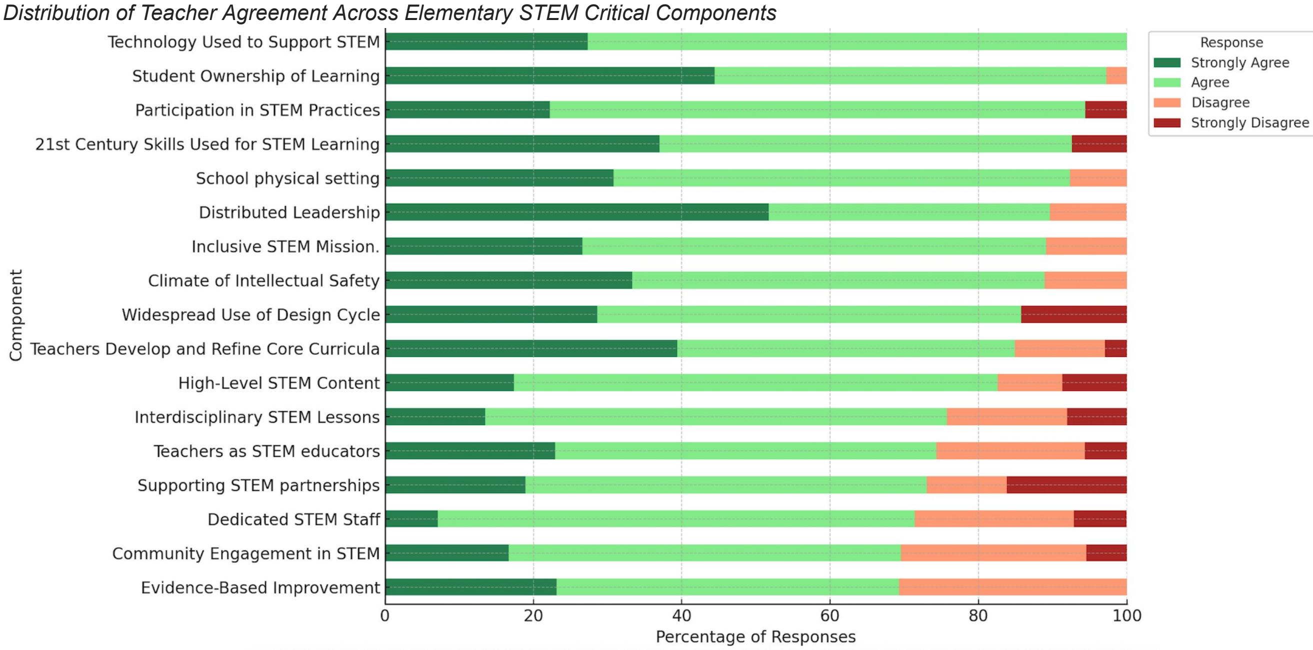
Inventory Findings from Teachers Across the School

To better understand the conversations that occurred with the early adopters, we present the results of the two inventories, which were shared with the group of early adopter teachers in order to focus on paths to improved integrated STEM programs in the lower and upper schools. This section is also offered to help administrators and teachers understand the components of schools that offer successful integrated STEM programs.

The critical components inventories were administered to all PK–12 teachers in the school. A total of 17 elementary and 13 secondary teachers responded to their relevant inventories. The secondary inventory indicated that, overall, the teachers felt confident in their ability to support student ownership of learning, to integrate technology and STEM practices into their instruction, and were well supported by responsive and innovative leadership, as can be seen in the visualization of that data in Figure 1. These areas reflect elements of instruction largely within teachers' control, suggesting that secondary teachers felt well-resourced and supported in implementing STEM effectively in their own classrooms. However, there was more variability in responses to components that extend beyond the individual classroom. Items related to Informal STEM Experiences and Connections with Business and Industry received lower levels of agreement. These results suggest less confidence in the school's broader capacity to support real-world STEM learning opportunities and cross-organizational collaboration.

Figure 1

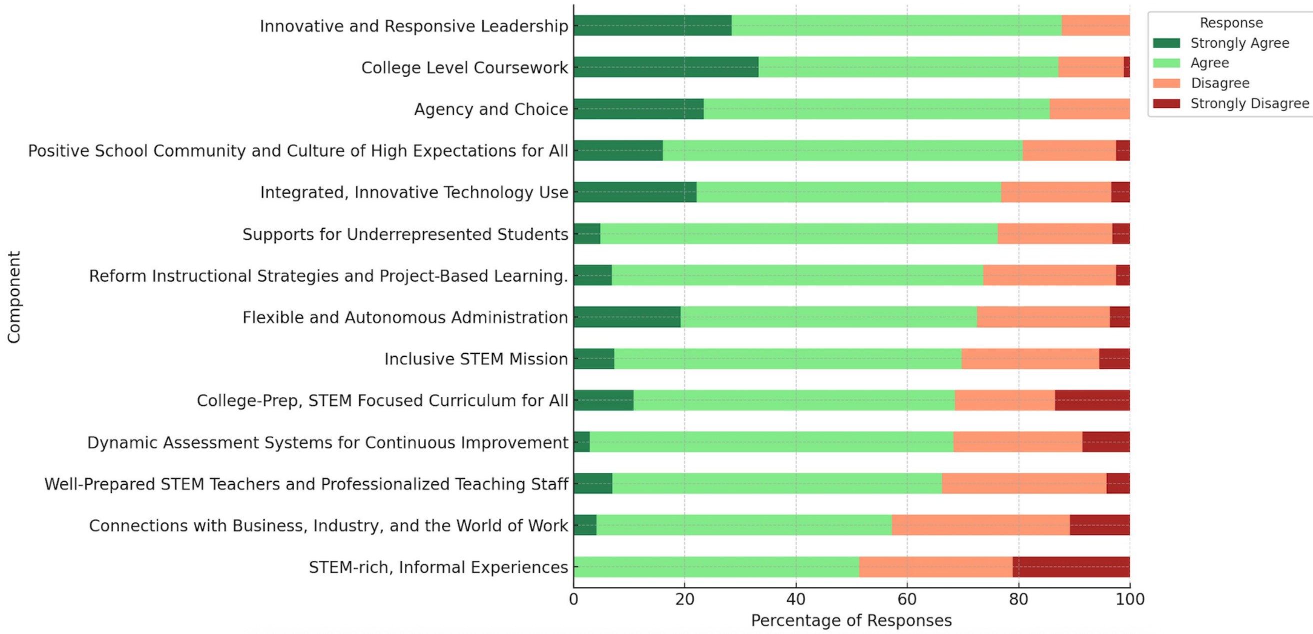
Distribution of Teacher Agreement Across Elementary STEM Critical Components



The elementary inventory revealed similar trends, with the elementary teachers expressing agreement in classroom-level components, including Technology Used to Support STEM, Student Ownership of Learning, and Participation in STEM Practices, as can be seen in Figure 2. These results point to a shared sense of autonomy, access to resources, and support for student-centered STEM instruction. However, components requiring coordination across the school or with external partners, such as Community Engagement in STEM, STEM partnerships, and interdisciplinary STEM, had more mixed responses. Evidence-Based Improvement also emerged as an area of mixed agreement, indicating uncertainty around how data is used to guide programmatic decisions. Together, this suggests that while teachers felt confident in their own STEM teaching, perceptions around opportunities to collaborate or extend STEM experiences beyond their own classroom appeared to be mixed.

Figure 2

Distribution of Teacher Agreement Across Secondary STEM Critical Components



When these findings were shared in the professional learning session with the early adopters, both elementary and secondary teachers noted that the results aligned with their own experiences. They acknowledged strong foundations in classroom STEM instruction with appropriate resources and support but pointed to a need for more clarity, structure, and support for whole-school and community-based STEM opportunities.

Decisions about Integrated STEM from the Early Adopter Teachers

The administrator and teachers expressed similar goals for this school improvement effort. Initially, the administrator wanted to offer higher-quality and quantity STEM offerings across the school to help students be more competitive in pursuing STEM fields.

“We have definitely given students in the past the foundation that they needed to be successful in STEM-related fields, but STEM-related fields are growing in their expectations for what students know. Coming into those fields is growing at such a fast rate. That’s a place in space where we’re working to grow as well.”

However, as the interview went on, the administrator identified STEM dispositional skills and critical thinking skills as a fruitful area to pursue for their school improvement.

“What I’m most excited about in our work together [with the research team] is this mindset between the dispositional skills that students need to be STEM-oriented and really deep thinkers and inquirers about the work that they’re doing, combined with the real-world application in the process that they’re going through.”

The group of early adopter teachers identified very similar goals for their school improvement efforts to those of the administrator. It should be noted that the administrator was not present for those sessions. During the initial days of the summer sessions, the early adopter teachers often discussed the challenges their students had with STEM learning. Many of the barriers they discussed are familiar (e.g., lack of time and a STEM expert in the elementary program, investigations becoming too ‘cookbook’ in secondary). However, across the grade levels, the teachers often spoke about how their students didn’t know what to do or even the types of questions to ask when they were starting a STEM project or activity. The social studies teacher described students as having a fear of failure. The biology teacher was the first to bring up the goal that she wanted her students to have more initiative in STEM projects and be more motivated to be independent learners. The mathematics teacher, who tried project-based learning for the first time in the previous year, noted that although it took longer than typical instruction, students learned a great deal of STEM thinking skills while they were building the “Kitchen Project,” such as collaboration and problem-solving. Although the early adopter teachers all agreed that their students were not yet comfortable with project-based learning, they wanted to find ways for students to learn how to think and communicate their thinking.

Identification of Self-Regulated Learning as an Important STEM Habit of Mind

In order to enhance STEM opportunities for their students, the group of early adopter teachers identified the initial goal of providing students with the habits of mind to think in ways that set them up for success. The teachers seemed to be particularly drawn to the SRL-related training and identifying explicit steps they could enact to support their students’ cognitive processes for engaging in STEM. The teachers decided to develop a series of initial questions for use across their various classrooms to support students in developing their SRL skills. On the final day of the training, the mathematics teacher shared a questionnaire she developed in response to the SRL-related training that contained specific questions intended to support students as they set goals, monitored their progress, and reflected on their outcomes aligned to Zimmerman’s SRL model (2000).

Analysis of the follow-up interviews indicated that two of the early adopter teachers decided to develop their students’ SRL skills explicitly, while another early adopter teacher decided to increase opportunities for students to develop their SRL skills independently. The mathematics teacher mentioned that she was still using the questionnaire she developed to explicitly support her students’ SRL skill development. Additionally, she spoke about how the questionnaire was supporting their students’ cognitive processes and enhancing STEM habits of mind:

“And what they’re starting to realize is, if they can tell me what they did wrong, they can adjust it, they can fix it. So, I do that on the homework, we do goal setting at the beginning of the year, the beginning of every chapter, and the beginning of every day.”

The questionnaire created by the mathematics teacher appeared to be gaining popularity at the school, and during the school year, other teachers asked: “Can I get a copy of that?” Similar to the mathematics teacher, the social studies teacher also appeared to be explicitly promoting the development of SRL skills by purposefully directing students to consider their cognitive processes in class:

“How do you want to study? What are the strategies you’re using to study? And then, you know, did you fall short of your goal? And what did you do to prepare for the test? So, to reflect on how you went about that.”

In contrast to the mathematics and social studies teachers, who each embraced explicit instruction of SRL skills, the biology teacher appears to have taken a more implicit approach to developing student SRL skills. By choosing to adopt a more student-centered approach to instruction that provides students with increased autonomy and choice, the biology teacher intentionally created opportunities for students to develop their SRL skills independently.

“I’ve usually been very, I’ve been all over them. And this year, I thought, okay, SRL says they have the wherewithal to problem solve. And they’re not going to develop the skills they need with someone hovering over them. So I literally closed my eyes and let them have at it. And when they need me, I check in. And it’s going surprisingly well…”

This more implicit approach allowed the teacher to become more familiar with moving to more student-centered instruction. Regardless of the approach, an analysis of the follow-up interviews suggests that several of the early adopter teachers decided to include SRL skill development in their classroom instruction.

Lessons Learned

Overall, the teachers and the administrator at the school we partnered with found this method of making decisions about strengthening STEM offerings to be strategic. The teachers and administrator knew they wanted to improve their STEM program across the school, but were unsure of how to go about it when they approached the researchers. The critical components of the inventories gave the teachers in all grade levels in the K-12 school a tangible way to think about their STEM offerings. The results of the inventories offered a systematic and research-based foundation for the group of early adopter teachers to reflect on what critical components they already did well and what they wanted to prioritize. From those results, the group of early adopter teachers could focus on what they wanted to improve and how to do it developmentally across K-12. This group of teachers focused on STEM habits of mind and helping students to self-regulate their learning. If this method were applied to another school setting, the focus of the early adopter teachers could be different, depending on the results from teacher responses in the inventories. Regardless of the focus and context, the inventories helped teachers and administrators focus on critical components, which streamlined initiatives into tried-and-true research-based elements for improvement rather than casting around for discrete ideas that were not connected to a framework or research.

The structure of the process and the organization of membership in each phase of the school improvement contributed to the effectiveness and flexibility of making decisions toward a stronger school-wide STEM program. We were able to gather ideas about STEM offerings from all members of the school through the inventories. From the results provided by the whole school, we met with a small group of ambitious teachers from a variety of grade levels who were willing to digest the information from the inventories and figure out what critical component(s) would be useful to strengthen in their classrooms. Finally, the teachers worked together to develop strategies for instruction that they then transferred to their developmental level for their students. The early adopter teachers will try out the chosen instruction and then develop ways to spread what worked in the other teachers’ classrooms until the whole school is teaching the strategy in each grade level. It was effective to start with a few teachers who made small changes in their instruction, and then take this grassroots effort and translate the school-wide initiative for scale-up in a way that takes into account teacher and student needs.

Finally, we found that the early adopter teachers were more interested in selecting skills rather than content for improving their STEM offerings across the school. The teachers noted that if students could learn self-regulated learning skills, then the STEM content would improve because the students would be ready for more rigorous content. We found in this study that not all of the teachers embraced an explicit way of supporting student self-regulated learning, and they first had to provide more opportunities for student choice and responsibility before they were willing to ask students directly about SRL processes. Although some teachers felt comfortable with more advanced and developed ways to talk about SRL explicitly with students, we recommend that the early adopter teachers consider ways to scale up that include all levels of teacher experience with the initiative.

Although our method of gathering information via validated surveys to begin early adopter group discussions worked well, in hindsight, we would have employed a few improvements. If others want to try this method of organizing STEM school improvement, we suggest more frequent meetings in the classrooms of the early adopters. Because we started designing the small interventions with the early adoption team in the summer, we were unable to see how they might work with their particular student population. We discussed teacher perceptions of students during this time, but were unable to make direct observations, thus unable to cater our particular knowledge of self-regulated learning to classroom implementation. We also suggest that research teams make a plan if there are changes in the early adopter group. In the following school year, the early adopter team notified us of a few teachers who left their positions at the school, leaving only three of the five original teachers. We have adapted by continuing discussions with a lead person (the STEM coordinator) at regular intervals so that any new changes in the plan can be modified in a timely manner. We suggest that future plans build in a point of contact/leader with the early adopter group early in the process.

In conclusion, this case study illustrates the potential of strategic, teacher-driven initiatives to enhance school-wide STEM opportunities. Leveraging the critical components inventories allowed a few early adopters to reflect on and identify strengths and areas for improvement in current STEM learning, allowing them to make more strategic, context-specific decisions. This approach offers a valuable model for schools seeking to build sustainable and systemic STEM programming from the ground up.

Supplementary Materials

Appendix 1. STEM-Focused Elementary (eSTEM) School Components Ratings Inventory
Appendix 2:Secondary STEM Schools Critical Components Inventory

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