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Science Instruction in STEM and Non-STEM High Schools

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ABSTRACT

This study compared science instruction in STEM and non-STEM high schools to determine how implementing a STEM instructional design impacts science, a cornerstone of STEM curricula. The goal was to gain insight into how the STEM school structure influenced the implementation of the science curriculum. The multiple case study examined STEM integration, science instruction, and students' perceptions of science instruction. Results from this study indicate that there are few differences in STEM and non-STEM schools' science instruction. Technology and mathematics integration were similar between all schools, but STEM schools integrated the engineering design process whereas non-STEM schools did not. This study offers insight into the implementation of STEM education within existing school contexts and constraints.

Keywords: science instruction, curriculum, pedagogy

Introduction

Science, technology, engineering, and mathematics (STEM) are significant components of learning and human culture (Hudley & Mallison, 2017; Rutherford & Ahlgren, 1990). The global issues facing humans today, such as providing universal access to clean water and sustainably feeding an increasing world population, will require citizens who are well versed in contemporary science and technologies (Rutherford & Ahlgren, 1990; Ritz, 2011). Furthermore, STEM education is increasingly a topic of education leaders' discourse, spurring calls for reform from respected academic, scientific, and business organizations (Kuenzi, 2008). One commonality from the discourse is the importance of preparing K-12 students to pursue STEM pathways in higher education in order to increase an innovative workforce (Gough, 2015; Thomasian, 2011).

High schools focusing on STEM are poised to support students' interest in STEM and persistence in STEM career pathways. However, the descriptive term "STEM" has been used ubiquitously throughout literature, often defined as an acronym in name, and is tied to school naming conventions indicating that the school is a STEM school. Furthermore, there is no one definition of STEM programs for high schools because the term STEM is defined and implemented differently depending on the context and location. For the purpose of this study, the term STEM is defined as a purposeful integration of science, technology, engineering, and mathematics' skills and processes and are examined here in a science classroom context.

This study focuses on science instruction as a key component of STEM education in secondary schools through a STEM ecosystem framework. Multiple case studies of science instruction were explored in four high schools in the U.S., two of which have been recognized by their state's Department of Education as STEM schools and two that were traditional comprehensive schools. The information collected from these case studies can provide insight into STEM program implementation and how STEM schools vary across different locations. Schools are increasingly redefining themselves as STEM schools and understanding how this is interpreted and implemented can inform STEM activities and instruction in schools to support student interest and engagement in science. In addition, there is little known about how the STEM educational approach influences science instruction.

Literature Review

The STEM Landscape

STEM education has garnered attention and interest as policy makers have promoted STEM programs in schools as a way to prepare students to pursue STEM career pathways (Thomasian, 2011). In 2010, the President's Council of Advisors on Science and Technology (PCAST) presented a report to the president of the United States calling to preparing students with a strong foundation in STEM content and inspiring students to pursue STEM careers. The council proposed creating STEM schools to improve STEM literacy (Holdren & Lander, 2010). This movement toward creating STEM schools has also been noted in Europe where the key elements of STEM schools have been identified and analyzed (Iglesias et al., 2018). The characteristics identified by the European researchers are very similar to those characteristics that have been identified in the U.S. and these are described below.

In some areas STEM schools emerged as a way to address inequities in precollege STEM opportunities and to increase student enrollment in underserved, often urban schools (Johnson et al., 2020). There is some evidence that STEM schools have experienced success in reducing the achievement gap for underrepresented students (Wiswall et al., 2014). Other studies have found mixed results for STEM schools in raising achievement (Gnagey et al., 2016; Young et al., 2011) and raising ACT scores (Means et al., 2016). Johnson et al. (2020) found STEM schools were successful in increasing underrepresented students' mathematics achievement. These preliminary studies argue for a more in depth look at how the STEM subjects are taught in STEM and non-STEM schools.

STEM School Models

According to the European study of STEM school characteristics, STEM schools have a unique curriculum that includes personalized instructional approaches, project and problem-based learning, and inquiry (Johnson & Sondergeld, 2020; Iglesias et al., 2018). The curriculum, according to these researchers, emphasizes STEM topics through an interdisciplinary approach, use of technology, and real-world connections. Another characteristic of a STEM school is the connection to businesses and industries in the community (Iglesias et al., 2018).

In the U.S., there is no single definition of a STEM school; however, the attributes of STEM schools that have emerged are almost identical to those identified in the European report. U.S. STEM school instruction typically involves inquiry that is student-centered and interdisciplinary ("Frequently Asked Questions | Ohio STEM Learning Network," n.d.). Several organizations report that STEM schools should have instruction that is project-based, problem-based, and should involve peer-to-peer learning (e.g., Maryland State STEM Standards of Practice, 2012; Robelen, 2013). Other definitions of STEM schools include the integration of technology, authentic assessment, and the promotion of business/community partnerships (Robelen, 2013). In order to gain a holistic, ecosystem view of the science instruction within STEM and non-STEM schools, this study focused on integration of STEM in science instruction as well as students' perceptions of instructional practices; attitudes towards science, mathematics, and engineering/technology; and STEM career interests.

Integrated STEM

Many STEM educators and researchers have argued that the acronym STEM is meant to convey the interconnectedness of the four discreet disciplines (Brown, 2012; Honey, Pearson, & Schweingruber, 2014; Guzey, Harwell, & Moore, 2014; Moore et al., 2014; Peters-Burton, Lynch, Behrend, & Means, 2014; Sanders, 2008). This does not mean that all four STEM content areas are integrated all the time, but rather that integrating the disciplines is strategic, blending content when and where it makes sense for the learning targets (Sanders, 2008). Honey, Pearson, and Schweingruber (2014) stated, "integrated STEM education includes a range of different experiences that involve some degree of connection. The experiences may occur in one or several class periods, throughout a curriculum, be reflected in the organization of a single course or an entire school" (p. 2). However, secondary schools typically teach science and mathematics separate from one another and may offer technology and engineering only as elective courses. One could argue that this separation of the four content areas of STEM creates fragmented knowledge and produces students who are not able to seamlessly integrate concepts within the STEM disciplines. Sanders (2008) stated, "amidst the realization that the T and E will play a critical role with regard to our welfare in the twenty-first century, the call for support has shifted from 'science and mathematics' to 'STEM'" (p. 25). There are many who disagree with this notion of integrated STEM, arguing that the disciplines are too complex and teacher education programs are not equipped to prepare teachers for meaningful integration (Lederman & Lederman, 2013). Another perspective is that each of the disciplines really are unique, and there is no such integrated discipline as STEM (Jones, 2009).

Theoretical Framework

The learning ecology model describes an interconnected system of relationships and environments providing learners an opportunity to learn (National Research Council, 2014; Traphagen & Traill, 2014; Barron, 2006). Metaphorically, this system represents an ecosystem. Learners are linked to multiple contexts (traditional, learning spaces) and communities of practitioners (educators, community members, or social groups) that are often guided by overarching policy and procedural protocols (National Research Council, 2014; Traphagen & Traill, 2014). The term ecosystem has an association with the biological sciences explaining how an organism, the smallest unit of size in the system, is connected to the environment composed of non-living components and living entities (other organisms and populations). In the context of education, the general design of the learning ecology model similarly parallels Bronfenbrenner's Ecological Theory. Ecological Theory proposes that an individual child is encircled by levels of relationships bound by cultural and economic contexts through time (Bronfenbrenner, 1979). These levels are described as systems: 1) microsystems: the direct relationships a child has with individuals such as parents and friends and in an educational context, teachers; 2) mesosystem: lateral connections between individuals identified in a microsystem such as the relationship between a teacher and parent; 3) exosystem: the cultural and economic parameters within a system such as societal support for education or funding available for educational efforts; and 4) chronosystem: recognizes that the system of relationships shifts over time (Bronfenbrenner, 1979). This theory situates an individual in a complex system composed of relationships and societal perceptions and has been applied to investigating public health issues and educational community partnerships and can provide a systematic structure for a STEM ecosystem approach in education research that targets factors that are likely influencing actions and decisions

(Leonard, 2011; Crosby, et al., 2011). The STEM ecosystem model has been applied in other STEM education contexts, such as K-12 teacher and administrator partnership with university STEM faculty (Tapprich, et al., 2016) and science hobbyists in an informal education context (Corin et al., 2015).

For this study, a STEM ecosystem approach was utilized to investigate science instruction within a learning ecology in recognized STEM schools and in non-STEM schools. The STEM ecosystem framework provides a model to illustrate the complex relationships of a learner (at the microsystem or organism level) within an educational web containing educators, community, and policy at varying levels within the ecological model. Traphagen and Traill (2014) portrayed a STEM ecosystem as "[harnessing] the unique contributions of all these different settings in symbiosis to deliver STEM learning for all children" to support STEM learning experiences and promote STEM throughout a learner's lifetime (p. 10). The learner is positioned within a centric location of the STEM ecosystem. Revolving around the learner are interconnected levels describing relationships and policies governing STEM learning experiences. These levels may include relationships with the learner as parents and teachers, community and cultural context of the learner, and school policies and expectations of science teachers and departments in school site context. The interactions within this ecological model facilitate the learner's experience within this ecosystem context. Because the STEM ecosystem is a complex system with multiple variables, levels, and relationships situated within time, this study's application of the framework focuses on science teachers' instructional design, which includes students' perceptions of instructional practice and attitudes towards STEM and STEM careers (Onwuegbuzie, Collins, & Frels, 2013). Consequently, this research focuses on how science instruction is implemented in STEM and non-STEM schools within varying levels of the STEM ecosystem.

Methodology

This multiple case study compared science instruction in STEM and non-STEM high schools to gain an understanding of the differences in STEM integration and science instruction in four high schools, two of which were recognized by the U.S. state as STEM schools. The research question guiding the study was are there differences between STEM and non-STEM secondary schools for the following:

RQ1: How is technology, engineering, and mathematics integrated in science instruction in STEM and non-STEM secondary schools?

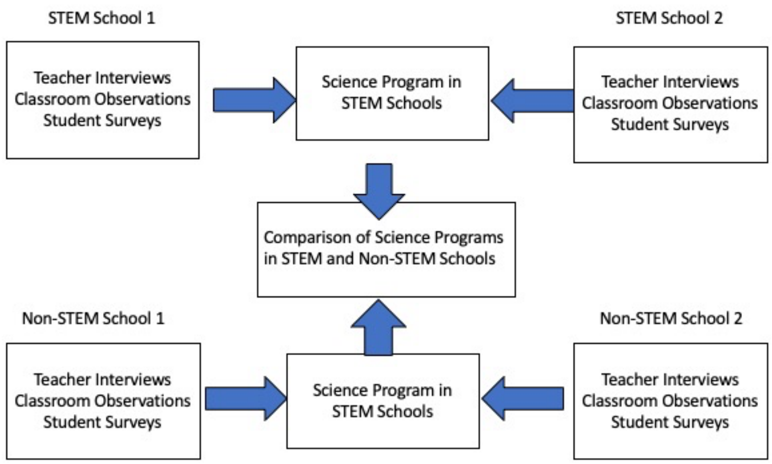
RQ2: What are the instructional and pedagogical methods used by science teachers in STEM and non-STEM secondary schools?

RQ3: How do STEM and non-STEM secondary students' perceptions of instructional practices; attitudes towards science, math, and engineering/technology; and STEM career interest compare?

Study Design

A case study design was employed to gain insight into science instruction at STEM and non-STEM secondary schools. The schools were all located in the southeastern region of the United States. The study focused on the science instruction within the schools, specifically documenting the science curricula taught in the schools and the instructional pedagogies facilitated by teachers within science classes. See Figure 1 (below) for an overview of the study design.

Figure 1. Study Design Documenting Science Programs and Instructional Pedagogies



The data collected for each school were analyzed to develop a case. Figure 1 shows the sources of data collected (teacher interviews, class observations, and student surveys) framed by the STEM ecosystem model.

Site and Participant Selection Process

The study occurred in a U.S. state with a process to officially recognize schools as STEM integrated schools. All high schools recognized by the state's Department of Education as STEM schools were invited to participate in the study. The first two to agree were included in the study.

STEM School 1: The first STEM school was an early college, in which students completed high school and up to two-years of college courses concurrently. Students applied to and were selected to attend based on predetermined criteria and number allotments.

STEM School 2: The second STEM school included was a catchment area school, in which the local school board created attendance zones and all students within that zone attended the school.

Once the STEM schools were selected and agreed to participate, the non-STEM schools were selected based on similarity to the STEM schools. State, district, and school level data released by the state's education department were imported into Tableau software, a tool that allows for data visualization (Grebing, 2015). Non-STEM schools were selected that matched the STEM schools as closely as possible in terms of student population and demographics, number of teachers, levels of free/reduced lunch, and school context (rural, suburban, urban).

All science teachers in the schools were invited to participate in classroom observations and a group interview. Out of 14 teachers who were invited, 7 STEM school science teachers and 5 non-STEM school science teachers agreed to participate in the study. Classroom observations were conducted of earth science, biology, and chemistry classes at each school as these were science courses offered at each of the four schools. All students enrolled in science courses at each school were asked to participate in a survey (described below). School and district demographic data are shown in Table 1.

Table 1. *Demographic Data of Participating Schools*

	STEM School 1 (Case 1)	*Non-STEM School 1* (Case 3)	*STEM School 2* (Case 2)	*Non-STEM School 2* (Case 4)
Total population of county	107,431	58,098	58,505	45,422
School size	341	278	728	834
Minority composition	26.1%	37.8%	81.6%	76.1%
Poverty composition	41.7%	49.2%	73.1%	56.6%

Data Sources

Data included teacher interviews, classroom observations, and student surveys. These multiple sources of data (described below) were used to provide and confirm information and to triangulate results.

Teacher Interviews

All science teachers at each school were interviewed in small groups using a semi-structured interview protocol. Interview questions were designed to elicit a general overview of the science curriculum and how technology, engineering, and math are integrated into science. Teachers were asked to describe their curriculum and a typical lesson, examples of how they use technology in instruction, barriers to using technology, and integration engineering and mathematics into their science lessons. All interviews were audio-recorded and transcribed verbatim for analysis.

Student Surveys

The student survey included items from the 2000 National Survey of Science Education Questionnaire (Weiss, et al., 2003) and the MISO survey that was designed to measure best practices, innovation, attitudes, and career interests related to STEM (Unfried, et al. 2015). Both surveys have been validated and found to be reliable (Weiss, et al., 2003; Unfried, et al. 2015). The 2000 National Survey of Science Education Questionnaire included a list of probable classroom activities and asked how often students participated in each of the tasks: listening to a lecture, analyzing data, writing reflections, and making presentations to the class. For each task, students indicated the frequency of student participation on a Likert scale with a scale from “never” a score of 1 to “most science lessons” a score of 5. The MISO survey (Unfried, et al., 2015) included scales for self-efficacy and beliefs as well as science teaching outcome expectancy with scores from 1 “strongly disagree” to 5 “strongly agree.” The MISO also included scales for student technology use that had a 6 point scale range of “never” to “not applicable.”

Classroom Observation

Science teachers were asked to volunteer for classroom observations at each school. Nine observations were conducted with the STEM school science classes (3 earth science, 4 biology, and 2 chemistry), and 7 observations were made in the non-STEM school science classes (2 earth science, 3 biology, and 2 chemistry). Not all schools offered physics so only the other subjects were observed.

The Classroom Observation Protocol, developed by Arshavsky et al. (2012), was used to document the types of instruction that observed. The observation protocol included four dimensions: mathematics and science content accuracy and presentation, meaningful and conceptual mathematics and science content, inquiry learning, and use of technology. Each dimension included multiple indicators rated on a 0-4 scale and a summary indicator rated on a scale of 1-4. The researcher was trained on the use of the instrument and inter-rater reliability of 0.92 using Cohen's kappa (1960) was found with a second trained coder.

Data Analysis

Qualitative data (teacher interviews and classroom observation protocol) were coded into the a priori categories of technology integration, engineering integration, mathematics integration, and science instruction. Data were analyzed to create a detailed description of each of the four cases and themes within the cases (Creswell & Creswell, 2013). Next, thematic analysis across the cases was performed to examine integration, and instruction.

Quantitative data collected from the student surveys were analyzed using the Mann-Whitney U test for three domains: Instructional Practice, STEM Attitudes Scores, and STEM Career Interest. The Mann-Whitney test was selected for the survey data because the groups were independent of each other and the survey items were on an ordinal scale (5 point Likert scale). All domains were analyzed with a two-tailed approach with adjusted alpha values (Bonferroni correction) to protect against error for each of the three separate domains. Adjusted alpha values for each domain are as follows: Instructional Practice (alpha = 0.003); STEM Attitude Scores (alpha = 0.017); STEM Career Interest (alpha = 0.004). Quantitative data collected from the Classroom Observations Protocol (4-point scale) was computed for each observed teacher by domain (content accuracy, meaningful and conceptual content, inquiry-learning, and use of technology. The scores were analyzed using the Mann-Whitney U test (two-tailed, alpha = 0.013). For all quantitative data, the mean rank, mean, standard deviation, Mann-Whitney U test statistic, p value, and effect size of significant differences for each scaled survey item were calculated (Field, 2013).

Methods for Verification

Data were collected from different sources (observations, interviews, and surveys) in order to answer the research questions and triangulate the data. Peer review was used throughout the process to provide an external check of the data coding and interpretation. As each case was developed, it was shared with the science teachers at the school for verification to ensure that the researcher's views matched the participants' views and to determine if any information was missing. In addition, rich, thick description was used to allow readers to make their own decisions regarding reliability (Creswell & Creswell, 2013).

Results

In the sections that follow, the descriptions of the case study schools (two STEM and two non-STEM) are presented followed by student survey responses and the comparison of school results. Thematic analysis within and across the cases is presented that describes science instruction in STEM and non-STEM high schools. Pseudonyms were used throughout the results to protect the identity of the participants.

Case One: Description of STEM School 1

STEM School 1, a STEM early college, is located in a large suburban county in North Carolina with a poverty rate of 16.7%. The school became a STEM school in 2014 and is located on the campus of the local community college in a two-story building. The school had two high school science teachers, and both teachers participated in the study. Mary and Barbara are Caucasian females with master's degrees and had 16 and 22 years of experience, respectively. The teachers were interviewed, and an earth science, two biology, and two chemistry classes were observed.

Students at *STEM School 1* are able to take earth science as freshmen, biology and chemistry as sophomores, and then college level science courses as juniors and seniors. Students have the option of pursuing an Associate's of Arts (AA) or Science (AS) degree. Students then take one college level science course for the AA degree or three college level science courses for the AS degree. Twenty students completed the student survey.

Case One: Integration of Technology, Engineering, and Mathematics in a Science Classroom

Technology

Mary and Barbara reported that freshmen and sophomore students at *STEM School 1* were issued iPads to use for instruction. In addition, teachers reported having access to laptop carts, Vernier probeware, and a 3D printer. Barbara and Mary reported that they used technology every day during science lessons, and students used technology multiple times per week to research, gather and analyze data, and communicate. Teachers used technology in each of the five lessons observed, but no student use of technology was documented during the observation sessions.

Engineering

Teachers reported several ways engineering was integrated into the science program and the school in general. For example, Mary invited engineers to speak to her biology and chemistry classes and excitedly described how she has incorporated the 3D printer; "I showed all of my classes how to use tinker cad and thingiverse. That's the coolest; they make something and then print it and see how it needs to be changed." She also stated, "I like to have them make things, like wind turbines, and test the voltage that is created." Barbara added that the school adopted an engineering design process to be incorporated into all classes in some way and "students completed an engineering design challenge as part of their seminar class." Both teachers emphasized the problem solving involved in engineering design and reported that students were regularly engaged in problem solving tasks. Engineering integration was not observed during classroom observations, but the engineering design process was displayed prominently in each classroom and in the hallway where you enter the school.

Mathematics

Barbara and Mary described the importance of mathematics in science classes, as exemplified in the following statements: "Data is important and we try to incorporate that as much as possible" (Barbara); "I feel like a math teacher some days" (Mary). Students were observed making calculations in a chemistry class as they reviewed for a test. When asked about collaboration between math and science teachers, Barbara described an instance of collaboration in which pre-calculus students participated in a pH lab experiment to develop the concept of logarithms. Mary added, "The other math teacher has a degree in engineering. They do a lot more math in context" which often included science related ideas.

Case One: Instructional Methods in a Science Classroom

Barbara and Mary described a typical week in a science class as consisting of lab experiments, data interpretation, short lectures, class discussions, practice questions, collaborative group work, and reading. When asked about inquiry-based learning, both teachers agreed that it was used at least weekly. Barbara described "inquiry can take lots of different forms; a web quest, experiment, trying to answer a broad question given a set of tools, or a design challenge with a set task." Project-based learning was included but "more common in earth science than in biology or chemistry" (Mary). Inquiry-based learning was present in three of the five science lessons observed and included students making ice cream to investigate energy, students presenting results of a classification project, and dissections to explore animal systems.

Case Two: Description of STEM School 2

STEM School 2's location is in a rural area with a poverty rate is 26.7%. The school opened in 1958 and received the STEM designation in 2014. The school had five science teachers, all of whom participated in the study (see demographic table below). Observations were performed of earth science, biology, and chemistry classes.

Table 2. *Science Teacher Demographics at STEM School 2*

Name	Gender	Race	Years of experience	Highest Degree
Patricia	Female	Caucasian	7	Bachelor's
Sally	Female	Caucasian	7	Bachelor's
Bette	Female	Caucasian	1	Bachelor's
Grace	Female	Caucasian	0	Bachelor's
Thomas	Male	Caucasian	2	Bachelor's

Students at STEM School 2 took earth science as freshmen, biology as sophomores, and physical science as juniors. More advanced students could take earth science and biology as freshmen. Once the requisite science courses were completed, students had the option to take chemistry, physics, AP biology, or forensic science. In addition, the school had a partnership with a local community college where students had the option to take college level science courses. Eighty-one students participated in the student survey.

Case Two: Integration of Technology, Engineering, and Mathematics in a Science Classroom

Technology

The five teachers in the science department shared two Chromebook carts, with 30 Chromebooks each, and one laptop cart, which had fewer working computers. They also had the option to use a computer lab in the library. Teachers reported utilizing technology in science classes at least weekly. Referencing specific uses of technology, Sally shared "…for some of my labs I don't have enough equipment, so we'll go on and do a virtual lab…my kids take all of their formative assessments online." Patricia noted that she facilitates "lab stations" in which students rotated to a different station. At each station, they watched a video, navigated illustrations, or read an article using a computer or Chromebook then answered questions. "I rely heavily on the document camera, [and] students do slow motion video on their phones to study centripetal force…" as stated by Thomas. Grace noted that she shared her PowerPoints on Canvas. Teachers were observed using technology to support lectures (PowerPoint) and to play video clips. One class of students was observed using laptops to explore various types and locations of volcanoes.

Engineering

Walking the halls of *STEM School 2*, one could observe the schoolwide engineering design process hanging on walls, as well as posters of engineering careers. Patricia explained that engineering design was "expected to be integrated into lessons monthly." Students were observed using the engineering design process in an earth science class to design and test structures that could withstand shaking from a simulated earthquake. Students were given a budget and simulated money, then required to design and purchase materials to construct and test their structure.

Mathematics

When asked about math integration in science, Grace listed several concepts that included math: "genetic variations uses a lot of fractions, cell surface to volume ratio, solution percentages, balancing equations, figuring out what molecules are going to look like and pair with, temperature ranges and looking at historical data, and graphing and plotting volcanoes and earthquake data." Thomas added, "Physics is algebra and pushes towards calculus. Chemistry, specifically stoichiometry, is heavy algebra, so I write the chemical equations and mathematical equations..." Sally described collaborating with a math teacher to use physical science formulas and situations in a math II class. Other examples of science and math integration were not readily known.

Case Two: Instructional Methods in a Science Classroom

Patricia and Sally described typical science lessons as including guided notes, independent and small group practice, videos, demonstrations, review games, and labs. Patricia went on to describe using inquiry-based labs in which students are given "a problem or situation to be solved instead of detailed instructions to follow." Students were observed participating in an inquiry-based simulation of protein synthesis in biology class, writing hypotheses in preparation for a lab in chemistry class, and designing earthquake-proof structures in earth science. In addition to inquiry-based lab activities, teachers reported using project-based learning at least once per instructional unit.

Case Three: Description of Non-STEM School 1

Non-STEM School 1, an early college high school, is located in a county with a poverty rate of 23.5%. The school opened in 2006. Non-STEM School 1 is split on two separate campuses that are 15 miles apart. The "lower school" campus houses freshmen, some sophomores, and older students who focus on career and technical (CTE) education, and the "upper school" campus houses some sophomores and older students who focus on college transfer classes.

The science department consisted of two Caucasian females, Katherine and Dorothy, and both participated in the study. At the time of the study, Katherine had a bachelor's degree and 17 years of teaching experience, while Dorothy had a master's degree, seven years of experience, and began teaching at the school in January of the current school year. Katherine and Dorothy taught at two different campuses. One each of earth science, biology, and chemistry classes were observed.

Students at Non-STEM School 1 took earth science, biology, and physical science during their first two years at the school. Some students went on to take chemistry and a college level science course. There was not a specific course pathway all students followed, but rather multiple pathways existed for students to accumulate course credits towards graduation requirements. Eighteen students participated in the student survey.

Case Three: Integration of Technology, Engineering, and Mathematics in a Science Classroom

Technology

Dorothy had a dedicated laptop cart in her classroom while Katherine described her access to technology as "very little" and then added: "We have two laptop carts we can check out, and they are shared among the four teachers…we had designated money for it, but the county is in financial binds and they took money from each school." Many students had cell phones that could be used in class and a few brought laptops or iPads from home. Dorothy described using technology every day for "virtual labs, research, or presentations." Katherine says she incorporates technology "two or three times per week" in similar ways as Dorothy with the addition of formative assessments. Students were observed using laptops in earth science to explore the lithosphere, and calculators and cell phones during chemistry lessons.

Engineering

Evidence for integration of engineering was limited. There was not a schoolwide engineering design process in use or evidence of engineering design projects. Katherine expressed that "the opportunities for those types of jobs are needed, but not in this area. There's not a demand for them in this area, so the kids are not geared into that." Dorothy previously taught in a STEM school and described including some engineering ideas in her science classes: "Whenever they have a problem, I coax them to think outside of the box. If there is something that isn't the way they want it, they are encouraged to go back and fix it. I don't call it the engineering cycle here, but I did at my previous school. Here I call it continuous improvement..."

Mathematics

Katherine and Dorothy spoke of the importance of math in science but had different experiences collaborating with math teachers. On the campus where Katherine teaches, the teachers meet for a few minutes every afternoon, as she described here: "We meet together and talk about what we're doing and exchange ideas, talking in general about managing classrooms, but we also get into the subject matter as well. We're good about working together, more so than at any school I've been at before." As a result of this frequent communication, science and math teachers had shared resources and ideas, but they had "not formally worked together" to integrate math and science content, according to Katherine. Dorothy was new to the school and working on a campus that did not have frequent meetings between teachers. When asked if science and math teachers collaborated, she answered "I'm sure they do, I don't see how you couldn't, but I don't know them well enough yet as I am still settling in. At one time, the math teacher borrowed two of my meter sticks, so I'm hopeful some science was involved there."

Case Three: Instructional Methods in a Science Classroom

Katherine and Dorothy described a typical week in a science class as including lectures with guided notes, students researching in small groups, vocabulary instruction and quizzes, and lab activities. Katherine described her classroom as "not very conducive for labs" due to having carpet and no running water or lab stations so she tends to use virtual labs. When asked about project-based learning, Dorothy described her students presenting "Frayer models" and "projects are just the labs" in chemistry class. Katherine stated that she gets project ideas from the internet but does not use them frequently. Students were observed performing a hands-on lab activity in which they followed instructions to learn about concentrations and molarity in a chemistry class. Students in earth science were observed creating solutions for human impacts on the lithosphere in small collaborative groups.

Case Four: Description of Non-STEM School 2

Non-STEM School 2's location is in a rural county with a poverty rate of 25%. The school had five science teachers, and three of them participated in this study (Willia: female, Pacific Islander, 16 years of experience, Master's degree; Abby: female, Caucasian, 5 years of experience, Master's degree; George: Male, Caucasian, 5 years of experience, Master's degree). A chemistry, earth science, and two biology classes were observed.

Students at *Non-STEM School 2* took earth science as freshmen, biology as sophomores, and physical science or chemistry as juniors. Students were advised to take chemistry if they were interested in attending college after high school, but they were free to choose between physical science and chemistry. Upon completion of the requisite science courses, students could choose to enroll in Advanced Placement (AP) chemistry, anatomy and physiology, and oceanography. AP environmental science was offered at another local high school and students could elect to take the course there, with transportation provided by the school, but no students at the time of the study took advantage of the opportunity. Twenty-three students participated in the student survey.

Case Four: Integration of Technology, Engineering, and Mathematics in a Science Classroom

Technology

Science teachers reported that the school had two computer labs they could reserve for their classes to use. George had three laptops in his room that students could use, one of those was his personal laptop. Willa had six computers received through grant funding. Most students brought smart phones to school, and they were provided access to the school's Wi-Fi. George described it as a "battle for the good things and not the bad things" in relation to regulating student phone use for instruction not social media. Teachers reported using technology for formative assessments, review games, and virtual labs. George mentioned that probeware used to be available, but the computers that ran the required software no longer functioned. He further explained, "The school doesn't fund those sorts of things. I got some Donors Choose money, but that's to restock my everyday chemical supplies." Abby added, "You end up spending your own money for basic things that should be in a school." Despite the lack of access, teachers were observed incorporating technology into lessons. Students were observed using computers in one biology class and cell phones in all other science classes. George attempted to use a virtual lab during earth science but the website did not work so he gave students an assignment using cell phones instead.

Engineering

Science teachers had not explored integrating engineering into science classes.

Mathematics

The science teachers easily provided examples of mathematics use in science class and described how mathematics is incorporated differently depending on the subject. Willa mentioned, "In physical science there is a lot: formulas, radioactive decay, graphing; about half the course is math". Abby shared that she believed that there was "…not a lot of focus on math in biology," so she incorporates math into labs and interpreting graphs. George stated that "Chemistry is all math, a couple of times a week, and it does depend on the unit…" However, he noted that collaboration with math teachers was limited.

Case Four: Instructional Methods in a Science Classroom

Willa and Abby reported collaboratively planning lessons since they teach the same course. Abby described a typical lesson: "We start with daily warm up. It's…based [on the state test] questions. Then if it's a new lesson we start with the new lesson, mostly it's direct instruction because I am crunching with time." George described his typical lesson: "We take the first ten minutes to review any homework…I'll reteach or go over specific problems, then collect the homework. I try to switch into whatever our new stuff is for the day…sometimes that might be a web simulator or a video…sometimes I will flip that and use the web simulator as the first thing and make it more inquiry based." Although the teachers described limited use of inquiry-based practices due to "blank stares from students" (Abby) and "the kids give up" (Willa), two teachers were observed using inquiry-based practices. In addition, students were observed working in collaborative groups with manipulatives and listening to lectures.

Survey Results - Student Experiences and Perceptions

Student surveys included data in three domains – instructional practices; attitudes towards science, math, and engineering/technology; and STEM career interest. Table 3, 4, and 5 show the comparisons between STEM and non-STEM school students' reported frequencies of instructional practices; attitudes towards STEM; and STEM career interest, respectively. Table 6 shows the comparisons between STEM and non-STEM science classroom observations. Mann Whitney tests were applied to determine if there were significant differences for student surveys and classroom observations.

Table 3. *Differences in STEM and non-STEM Student Responses by Instructional Practice*

Survey Item	STEM Mean Rank (Mean, SD)	Non-STEM Mean Rank (Mean, SD)	Mann Whitney U	*p* value (effect size)
1. Listen and take notes during a presentation by the teacher	74.54 (4.50, 0.81)	66.10 (4.30, 0.94)	1896.50	0.267 (0.09)
2. Watch a science demonstration	71.22 (3.43, 1.08)	73.80 (3.49, 1.08)	2072.50	0.728 (0.03)
3. Do hands-on/laboratory science activities or investigations	74.45 (3.69, 1.01)	69.56 (3.51, 1.22)	2045.00	0.522 (0.01)
4. Follow specific instructions in an activity or investigation	69.86 (4.04, 1.08)	77.15 (4.21, 1.02)	1904.50	0.337 (0.08)
5. Design or implement your own investigation	68.27 (2.67, 1.56)	80.67 (3.00, 1.20).	1777.00	0.101 (0.14)

6. Participate in field work	72.43 (2.7, 1.31)	71.00 (2.67, 1.49)	2107.00	0.849 (0.02)
7. Answer textbook or worksheet questions	63.02 (3.47, 1.37)	92.87 (4.47, 0.63)	1252.50	0.000* (0.33)
8. Record, represent, and/or analyze data	68.49 (3.43, 1.04)	78.42 (3.72, 1.08)	1831.00	0.187 (0.11)
9. Write reflections (ex. in a journal)	70.47 (2.66, 1.34)	77.28 (2.88, 1.35)	1966.00	0.373 (0.08)
10. Make formal presentations to the rest of the class	67.91 (2.76, 1.01)	78.81 (3.20, 1.38)	1707.50	0.152 (0.12)
11. Work on extended science investigations or projects (a week or more in duration)	68.74 (2.79, 0.94)	76.14 (3.07, 1.20)	1886.00	0.322 (0.08)
12. Use computers as a tool (ex. spreadsheets, data analysis)	66.03 (3.33, 0.96)	87.69 (3.86, 1.04)	1518.5	0.004 (0.24)
13. Use mathematics as a tool in problem solving	70.86 (2.83, 1.12)	76.36 (2.98, 1.20)	2005.5	0.472 (0.06)
14. Take field trips	81.37 (2.17, 1.09)	51.67 (1.51, 1.05)	1276.0	0.000* (0.33)
15. Use an engineering design process to solve problems	78.96 (2.34, 0.99)	57.34 (2.14, 1.32)	1519.5	0.005 (0.14)

Note: Mann Whitney U: Differences in two independent groups, Alpha 2-tailed, $*p<0.003$ on a 5-point Likert Scale

Significant differences were observed for two survey items. Non-STEM school students reported answering textbook or worksheet questions (survey item #7) at a higher frequency whereas STEM school students reported taking more field trips (survey item #14) with small effect sizes (Rosenthal, 1996).

Table 4. *Differences in STEM and non-STEM Student STEM Attitude Scores*

Attitude Domain	STEM Mean Rank (Mean, SD)	Non-STEM Mean Rank (Mean, SD)	Mann Whitney U	*p* value (effect size)
Science	62.39 (3.38, 0.81)	73.03 (3.62, 0.73)	1462.0	0.144 (0.13)
Math	62.28 (3.36, 0.96)	73.30 (3.63, 0.76)	1451.5	0.129 (0.13)
Engineering/Technology	63.13 (3.23, 0.83)	69.49 (3.37, 0.71)	1558.5	0.379 (0.07)

Note. Mann Whitney U: Differences in two independent groups, Alpha 2-tailed, $*p<0.017$ on a 5-point Likert Scale

No differences were observed between STEM school and non-STEM school students' STEM attitude scores.

Table 5. *Differences in STEM and non-STEM Student Career Interest*

Career Area	STEM Mean Rank (Mean, SD)	Non-STEM Mean Rank (Mean, SD)	Mann Whitney U	*p* value (effect size)
Physics	59.40 (2.16, 0.86)	76.58 (2.58, 0.83)	1251.0	0.017 (0.20)
Environmental work	61.85 (2.24, 0.82)	72.54 (2.5, 0.83)	1442.5	0.139 (0.12)
Biology and Zoology	60.01 (2.36, 0.90)	76.96 (2.79, 0.91)	1274.5	0.019 (0.20)
Veterinary work	61.13 (2.39, 0.94)	72.47 (2.68, 0.93)	1407.0	0.114 (0.13)
Mathematics	62.19 (2.20, 0.97)	68.25 (2.37, 1.00)	1529.5	0.395 (0.07)
Medicine	58.86 (2.56, 1.04)	77.86 (3.11, 0.89)	1202.5	0.008 (0.22)
Earth Science	60.24 (2.18, 0.82)	72.80 (2.50, 0.83)	1356.5	0.078 (0.15)
Computer Science	63.16 (2.36, 1.00)	64.31 (2.38, 0.89)	1616.5	0.873 (0.01)
Medical Science	58.76 (2.46, 0.97)	76.74 (2.95, 0.97)	1193.5	0.012 (0.21)
Chemistry	61.84 (2.31, 0.98)	70.80 (2.55, 0.95)	1470.5	0.211 (0.10)
Energy	64.57 (2.06, 0.91)	64.34 (2.05, 0.91)	1677.5	0.976 (0.00)
Engineering	65.36 (2.34, 1.01)	64.13 (2.29, 0.96)	1695.0	0.865 (0.01)

Note. Mann Whitney U: Differences in two independent groups, Alpha 2-tailed, $^*p<0.004$ on a 5-point Likert Scale

No differences were observed between STEM school and non-STEM school students' STEM career interests.

Table 6. *Differences in STEM and non-STEM Science Classroom Observations*

Scoring Dimensions	STEM Mean Rank (Mean, SD)	Non-STEM Mean Rank (Mean, SD)	Mann Whitney U	*p* value (effect size)
Content accuracy	9.61 (3.89, 0.33)	7.07 (3.57, 0.53)	21.5	0.313 (0.25)
Meaningful and conceptual content	9.17 (2.22, 0.83)	7.64 (2.00, 0.58)	25.5	0.562 (0.15)
Inquiry-learning	9.17 (2.44, 1.33)	7.64 (2.00, 1.15)	25.5	0.562 (0.15)
Use of technology	8.94 (1.56, 0.73)	7.93 (1.43, 0.79)	27.5	0.711 (0.09)

Note. Mann Whitney U: Differences in two independent groups, Alpha 2-tailed, $^*p<0.013$ on a 4-point Rubric Scale

No differences were observed between STEM school and non-STEM school science classroom observations. In the following sections, themes are analyzed across the four cases to answer the research questions.

Comparison of Schools

Integration of Technology

Of the four schools, *STEM School 1*, had the most access to technology. However, teachers in all four schools reported integrating technology into science lessons at least weekly. Observed technology integration scores ranged from 1 to 3 on the 4-point scale used in the protocol; most of the observed lessons were rated at level 1 or 2, and one level 3 lesson was observed in each category (STEM or non-STEM) of school. Teachers at each school discussed aging technology as a barrier to integration. George (Non-STEM School 2) shared "A decade ago that existed here, but the computers that run the software are all Macs, but they are slow as molasses. The couple probes I have – before I came here whoever used them stopped using them and they dried up. So, there weren't a lot and the ones I have weren't maintained. The school doesn't fund those sorts of things."

Integration of Engineering

A schoolwide engineering design process was in use at both STEM schools in this study. When asked how frequently engineering was incorporated into science, Patricia at STEM School 2 responded, "I would say probably about once a month. I know that all the earth science classes do the earthquake unit, and they design a structure to withstand an earthquake and use the design process to do that. I have a photosynthesis and cellular respiration project where students design products that they can sell that runs off of photosynthesis or respiration. Physical science designs solar ovens to cook s'mores, and they've done rubber band cars and raced those..." The slight difference in use of an engineering design process did not result in a difference in students' interest in careers in engineering as shown in Table 5. In addition, students' attitude scores towards engineering and technology were 3.25 and 3.37 for STEM and non- STEM students, which was not significantly different.

Integration of Mathematics

All the teachers interviewed agreed that math is important to and used frequently in science. Katherine (Non-STEM School 1) stated "I use it as much as I can because kids struggle with the math more than the science. I get frustrated when I have a tenth grader who cannot rearrange or solve for a variable." At Non-STEM School 2, George shared that there is a lot of graph interpretation. He also noted that "As far as chemistry, there are a lot of calculations, and helping kids to see the connection between variables in an equation and how things are actually changing. For example, we are reviewing gas laws this week, and so if you increase your pressure how is that going to increase the volume?" However, integration of mathematics was not reported as being purposeful and collaboration between math and science teachers was limited. Sally (STEM School 2) remarked "The only collaboration I've done is strategies for getting math concepts across. For example, I have kids that can't get how to rearrange an equation, so I ask how they get them to do that." Katherine (Non-STEM School 1) shared "I have not, we have given each other some material and exchanged ideas, but we haven't really tried to collaborate. We want to improve upon that because [the principal] wants to see that too." Students' mathematics attitude scores were similar between STEM and non-STEM schools at 3.36 and 3.63, respectively.

Instructional Methods

Science teachers in the four schools used a variety of instructional practices. Many teachers interviewed described using whole class direct instruction followed by an activity, lab, or virtual investigation. Several teachers including Patricia (STEM School 2), Mary (STEM School 1) and Dorothy (Non-STEM School 1) shared that *lecturing*, *taking notes*, and *practicing problems* are the most utilized instructional practices. Inquiry-based learning was observed in every school, but it was not the dominant instructional tool teachers used. Table 6 displays inquiry-learning scores from the classroom observation protocol. There were no significant differences between STEM and non-STEM schools for the uses of inquiry, which included project-based learning. Project-based learning was observed at the STEM 1 school and was described by teachers at the non-STEM 1 high school. The two non-STEM schools had little evidence of project-based learning. The student survey revealed that students in the two non-STEM schools more frequently reported spending class time answering textbook and worksheet questions, see Table 3. Other instructional practices were found to occur at similar rates.

Limitations

Though every effort was made to select comparison schools with similar characteristics and contexts, schools are inherently complex systems and natural differences will exist between them. The results could be different if another lens, for example mathematics or engineering, was used. The duration of the study provides only a snapshot of the schools and data collected only accounted for viewpoints from science teachers and students.

Discussion

This study was motivated by a desire to look beyond the rhetoric surrounding STEM education to see what happens when those ideals are put into practice. Framed within the STEM ecosystem model, the goal of this study was to compare science instruction within STEM and non-STEM secondary schools. The case studies, while not broadly generalizable, provide insight into how two STEM schools enacted the ideals of STEM education within their unique contexts and communities in comparison to non-STEM schools.

STEM Integration

Interdisciplinary learning is not a new idea (Conderman, Crawford, & Frankenberger, 1996; Monhardt & Henriques, 1997; Roucher & Lovano-Kerr, 1995); however, in recent years, the conversation has narrowed in many contexts to integrating the STEM disciplines specifically. This study showed that science teachers in all four schools included technology in their science instruction and teachers in STEM schools included engineering design in instruction directly impacting students at the microsystem level. Science teachers in the STEM schools had some knowledge of mathematics teachers' practices and had engaged in some collaboration but did not consider their integration of mathematics "purposeful." The following sections explore technology and engineering integration further to describe the emergence of mesosystem levels of interaction between teachers.

Technology

The finding that technology integration was similar across STEM and non-STEM schools is not surprising as schools across the nation are figuring out how to produce technologically competent graduates who are prepared to enter college or the workforce. Teachers were observed using technology as a replacement support for traditional whole class direct instruction in both STEM and non-STEM schools; instead of writing on the chalk board or overhead projectors, teachers used PowerPoint to give students notes. Students were observed using technology for formative assessment (online quizzes) and virtual labs, again examples of replacing traditional modalities rather than transforming teaching and learning. None of the observed lessons received a score of four on the technology dimension of the protocol, which would have indicated that technology was used to transform the instructional method, learning process, or the subject matter. Instead, most observations earned a score of one or two on the observation rubric, indicating that technology use was limited or used to replace established instructional practices, learning processes, or content goals. Even in STEM School 1, with its increased access to technology, classroom use of technology was not transformational. Technology use outside of class time was not deeply explored in this study; however, students at STEM School 1 had access to technology, like 3D printers and ROVs, after school and during study halls. It is not known how this access impacts students' future career or hobby choices. In addition, STEM School 1 students participated in an Hour of Code and Girls that Code, both new computer coding programs for the school. It is not clear if continued participation in those events would impact students' ideas about technology.

Engineering

The rhetoric surrounding STEM typically includes engineering integration to be accomplished through the pervasive use of a schoolwide engineering design process. Both STEM schools had adopted a schoolwide engineering design process that was used in every class and teachers reported instances of engineering integrated into science classes. A lesson using engineering design was observed; however, a pervasive use of the engineering design process as a problem-solving framework (Dym et al., 2005) was not observed. It is not known if using an integrated engineering design process is the best way to teach engineering or if students should take specific engineering courses. Furthermore, the quality of the engineering integration was not examined and there was no evidence that this integration enhanced students' understandings of science. With already overburdened science curricula, one could argue that adding engineering could dilute science learning. Furthermore, this study did not examine engineering integration that might be present in mathematics, social studies, or English classes, although the STEM schools had a schoolwide engineering design process in place. Further studies are needed to explore engineering integration in those other content areas.

Science Instruction

Science instruction was not appreciably different between the STEM and non-STEM schools in the study. Teachers in both STEM schools reported using project-based learning and a project-based lesson was observed at STEM School 1; however, this did not result in a greater frequency of inquiry-based practices as reported in Table 6. Three schools in the study are in low-wealth districts and the drivers of instruction are more alike than different: test scores, diverse populations, and lack of money for supplies. Several teachers mentioned a lack of time as an obstacle for inquiry-based instruction. With over-packed curricula and high-stakes testing, teachers may feel pressure to move quickly and disseminate information, instead of spending time enculturating students into the processes of science as Priest (2013) suggested. STEM schools and non-STEM schools alike are held to statewide testing mandates; schools are not allowed the flexibility to test out new designs in a low risk environment. The ideologies of STEM education may have the potential to improve student performance in science and math, but teachers would need time to learn and practice new strategies at the exosystem level. Alternatively, it is not clear whether science instruction benefits significantly in a STEM school compared to a non-STEM school.

Implications for Further Study

This study used a STEM ecosystem model to frame how STEM was enacted in schools and focused on science instruction specifically. Although this study only considered the views held by science teachers and students within the ecological learning system at the specific micro- and mesosystem, school and district administration, community members, parents, and teachers in other departments also take part in the implementation of STEM education within schools and their perspectives require further examination within the larger exosystem context. The political drivers for the push to become STEM schools were not examined in this study. While science, technology, and mathematics are present, to some extent, in every school, non-STEM schools are missing teaching the engineering domain. Where is the push for more engineering instruction coming from and should all students learn engineering? There have been arguments presented for a lack of qualified workers to fill engineering sector jobs, which represent a portion of our economy, but arguments to the contrary have also been made (Kelly, Butz, Carroll, Adamson, & Bloom, 2004).

The two STEM schools included in this study have had a STEM focus for three years. Presumably, their implementation of STEM could deepen over time, producing differences in student attitudes and dispositions that were not observed in this study. Alternatively, since staff within these schools have not been stable, teachers and administrators have moved to other positions and been replaced with new staff members, the champions of STEM could transition out of the schools and the STEM focus could stagnate. What sustains and motivates schools and teachers to continue in pursuing a STEM focus in their instruction? There was no additional compensation received for being a STEM school, so what triggers a teacher or school to stay on this path? Does the community view a school differently if it has STEM instruction? Are there benefits to a school district for encouraging schools to focus on STEM as opposed to each science and engineering domain?

Results indicated that students' attitudes toward STEM instruction were similar between STEM and non-STEM high school students. Does this pattern continue with age? Student achievement in science and math was not studied, is it different in STEM schools? If it is different, do STEM students achieve higher in one or more of the STEM domains in college and does this impact their attitudes towards their work? These questions suggest that further research is needed to provide evidence about the degree to which STEM instruction makes a genuine difference in the quality of science instruction.

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