J-STEM

Journal of Research in STEM Education

Vol 4, No 2, December 2018

j-stem.net

EDITORIAL BOARD

Contact

All queries related to manuscript submissions can be directed to Dr. Aydeniz, the Editor-in-Chief, jstemeditor@gmail.com

Mehmet Aydeniz, PhD.
Associate Professor of Science Education.
Program Coordinator, Science Education.
Department of Theory and Practice in Teacher Education
The University of Tennessee, Knoxville
A 408 Jane & David Bailey Education Complex
Knoxville, TN 37996-3442
USA
Phone: +1-865-974-0885

Publisher / Founder : i-STEM / Gultekin Cakmakci

ISSN:2149-8504

Contents

ISSN:2149-8504 (online)

Journal of Research in STEM Education

Vol 4, No 2, December 2018

EDITORIAL

Mehmet Aydeniz[a], Lynn Hodge[a], Gokhan Kaya[b], Noleine Fitzallen[c]

[a]The University of Tenesse, Knoxville, USA
[b]Kastamonu University, Turkey
[c]University of Tasmania, Australia

In this issue of the Journal of Research in STEM Education, we present seven unique contributions. The first article by Schwab, Cole, Desai, Hemann, Hummels, and Maltese (2018) present findings related to a summer STEM program. The purpose of the project is to increase middle and high school students' interest in STEM careers while engaging in STEM programing and to help graduate students to develop pedagogical knowledge related to teaching. Authors provide details of the Foundations in Science and Mathematics program (FSM) program and explore its impact on student learning.

The second article by Genareo, Kemis and Raman (2018) investigates students' conceptions of engineering at the beginning and end of their involvement in a National Science Foundation funded Graduate STEM Fellows in K-12 Education (GK-12) program. It examines whether students involved in the program exhibited greater conceptions of engineering from beginning to end, whether differences exist among males and females, and if students' engagement and satisfaction with their Fellows affects growth in conceptions of engineering. Pre-survey and post-survey data were collected annually over four years from 1,522 participants in grades 7 and 8 who had a GK-12 Fellow.

The third article of this issue by JeanPierre (2018) explores the inquiry beliefs and practices of an elementary teacher in an urban low SES school. The case study included an array of data collection methods: teacher interview, classroom observations of teacher's practices (3-5) days a week over six months, weekly journal reflections, teacher's responses to an inquiry survey. Findings indicated that the teacher's beliefs and practices did align and that she did consistently use structured and guided inquiry practices, but rarely used "full inquiry" as described in the National Science Education Standards. Key to this teacher's use of inquiry was the professional education she had received that both modeled and provided opportunity for her to use various inquiry practices.

Arnone and Hanuscin (2018)' s article examines and describes the ways in which elementary teachers conceptualize iSTEM Education and the integrative approaches they use when teaching STEM content, with the intent to inform the development of elementary specific iSTEM Education professional development.

Tyler-Wood, Johnson, Cockerham (2018)'s study examined factors that influence middle school students' dispositions towards science, technology, engineering, and math (STEM) careers. Interest and ability in STEM subject areas were compared by gender, based on 182 middle school students' responses to four different test instruments. The findings of this study underscore the challenges that still exist in achieving equal gender representation in the STEM workforce, and suggest that adopting a constructivist learning approach may provide a foundation for girls to develop a more positive approach toward science, boost STEM awareness and interest, and increase STEM success.

Peters-Burton, House and Lynch (2018)'s contribution examined the curriculum and instruction occurring at high performing STEM-focused high schools that have no academic conditions for student admission. By conducting a cross-case analysis across eight case studies of contextually different but well-regarded inclusive STEM high school, they found that different themes emerged across these schools. These themes included different hierarchical levels of design and implementation (classroom-level, cross-cutting school level, school-wide) as well as responsive design of curriculum and instruction. They discuss unique contextual differences as well as implications for replication of inclusive STEM school design.

ISSN:2149-8504 (online)

The final paper of this issue by Aydeniz and Bilican (2018) explored the weaknesses and strengths in pre-service primary teachers' (PST) conceptualization of STEM and their knowledge of STEM pedagogy after engaging in integrated STEM (science, technology, mathematics and engineering) activities for one semester. The course activities emphasized concepts related to engineering design process, the interrelatedness of STEM subjects, inquiry and problem solving. Results show that engaging students in immersive STEM activities helped PSTs develop foundational knowledge regarding STEM, engineering design and STEM pedagogy, which they could built on later to more effectively teach through STEM integration. Discussion focuses on how PSTs and practicing teachers can be supported through sustained professional development for STEM integration.

Collectively, these articles make unique contributions to our collective understanding of issues related to STEM education.

ISSN:2149-8504 (online)

Journal of Research in STEM Education

Vol 4, No 2, December 2018, 117-129

RESEARCH REPORT

A Summer Stem Outreach Program Run By Graduate Students: Successes, Challenges, And Recommendations For Implementation

Daniel Bryan Schwab[1], Logan Wyatt Cole, Karna Mahadev Desai, Jason Hemann, Katherine Ruth Hummels, Adam Vincent Maltese

Indiana University, USA

Abstract: *Providing science, technology, engineering and mathematics (STEM) experiences to middle and high school students outside of traditional classroom settings is critical in preparing learners to be literate in these fields. At the same time, providing graduate students in science and mathematics with independent pedagogical opportunities that prepare them to effectively teach and communicate STEM subjects to the general public are exceedingly rare. Here, we present the Foundations in Science and Mathematics program (FSM), a rapidly growing summer STEM educational program operated entirely by graduate students at Indiana University, Bloomington, that seeks to achieve both of these goals. First, we detail the organization and scope of FSM, the extent to which it grew since its founding in 2011, and the general aims and design of its courses. Second, we address the demographic composition of the program, and evaluate its pedagogical success through learning evaluations and student surveys that gauge student academic improvement and course satisfaction, respectively. Overall, we find that FSM significantly increased student learning and that courses were given favorable reviews by students. Finally, we discuss the logistical operation of FSM, with the goal of assisting motivated graduate students in developing similar programs at other academic institutions. In combination, we find that FSM was highly successful at achieving its goals of enhancing student learning and promoting effective pedagogy among graduate students, and we encourage other institutions to establish similar programs in their own academic communities.*

Keywords: Secondary education, Extracurricular STEM Activities, STEM graduates

Introduction

Though access to a high-quality science and mathematics education is widely sought after, providing students with such educational opportunities outside the classroom can be a major challenge, as many existing opportunities are cost-prohibitive or regionally unavailable (Allen & Chavkin, 2004; Cook et al., 2015). Universities can play a unique role in filling this void in their communities, as science and mathematics departments possess intellectual and material resources otherwise unavailable to local K-12 schools, and graduate students are often eager to gain experience in teaching and pedagogy (Tanner and Allen, 2006; Reeves et al., 2018). Indeed, while graduate students may serve as teaching assistants, these appointments are often limited in scope, providing few or no opportunities for independent instruction or curriculum development (Davis and Kring, 2001; Cherrstrom et al., 2017). Therefore, extant teaching opportunities often fail to sufficiently prepare graduate students to teach independently and develop effective curricula (Parker et al., 2015; Kim et al., 2017).

[1] Corresponding Author: Daniel B. Schwab, Department of Biology, Indiana University 915 East Third Street, 102 Myers Hall Bloomington IN, 47405-7107. Contact: schwabd@indiana.edu

Schwab, D. B., Cole L. W., Desai, K. M., Hemann, J, Hummels, K. R., & Maltese, A. V. (2018). A Summer Stem Outreach Program Run By Graduate Students: Successes, Challenges, And Recommendations For Implementation. *Journal of Research in STEM Education*, *4*(2), 117-129.

ISSN:2149-8504 (online)

Further, although graduate students increasingly participate in local outreach and "scientist in the classroom" programs, these are generally short in duration (often lasting a day or less), and present few opportunities for feedback and assessment (Laursen et al., 2007; Ufnar, 2017). This paper describes a program that attempts to address the needs of both groups to a substantial degree, providing secondary students affordable enrichment in the sciences and mathematics, while giving graduate students more substantial and autonomous opportunities for teaching and curriculum development.

The Foundations in Science and Mathematics (FSM) program is a graduate student-led summer educational program for middle and high school students now in its eighth year at Indiana University, Bloomington (IU). This program seeks to accomplish four primary objectives: i) to supplement the STEM education of local middle and high school students, in part by ii) fostering collaboration between IU and local educational institutions, while iii) providing independent teaching and curriculum development experiences to graduate students, and iv) allowing graduate students to develop program management, leadership and communication skills. The program began in 2011 with fewer than 60 high school students, and only four remedial/preparatory courses in mathematics and physics (Bennett et al., 2012; Timme et al., 2013). Since that time, FSM grew substantially; its annual enrollment and course offerings are a substantial component of IU's pre-college outreach efforts, and it is now a well-established feature of the local educational ecosystem. In the following sections, we provide an overview of FSM, discuss its demographic composition and student-learning achievements, and share our successful strategies for maintaining and growing the program. We share this to enable others to bring FSM to their campus or to develop similar programs.

Program Overview

The FSM program offers preparatory, supplementary, and exploratory courses in science and mathematics for approximately 150 area middle and high school students each year. Graduate students are responsible for the entire operation of the program, and do so at two levels including i) as instructors who teach courses commensurate with their disciplinary expertise and ii) as administrators who handle logistic and budgetary concerns. The program consists of two individual two-week sessions, one held in June and the other in July, and offers approximately a dozen distinct STEM courses in each session. Traditionally, these courses included introductory and advanced instruction in core high school biology, chemistry, physics, and mathematics (e.g. algebra, calculus, trigonometry) content, with more recent and interdisciplinary course offerings including astronomy, astrophysics, brain science, the chemistry of food, computer programming, environmental science, evolutionary biology, forensic science, and zoology – offerings that go beyond typical curricula. Each course has a limited enrollment of up to fifteen students and meets for two hours per day, three days per week during the two-week period, for a total of twelve hours of instruction time. In addition to demonstrations and lecture-based instruction, class meetings utilize active learning strategies with hands-on activities (see Appendix for an example), group work, and discussion to improve learning and engagement (Freeman et al., 2014; Schwartz et al., 2016). Each course focuses on foundational concepts and introductory materials, with a special emphasis on analytical and quantitative reasoning skills, and aims to improve students' background and confidence with the material. At the end of each session, the program provides students the opportunity to tour IU research facilities in order to provide them with an understanding of how the concepts learned in their classes apply to contemporary research programs.

Curricula for FSM courses are conceived of and developed using a variety of different sources. Instructors preparing courses for required or core school subjects, for instance, use Indiana state standards (including ISTEP+ standardized testing requirements) and College Board Advanced Placement standards to guide curriculum development. In many cases, these standards are reviewed with local teachers who highlight topics that are of particular importance or are especially challenging for students. The framework that these standards and the teachers provide allows FSM to design preparatory courses that align closely with the curricula of students' base schools. To familiarize students with the subject matter, courses attempt to capture as much of the breadth of their intended subject as reasonably fits in the two-week time constraint. This time constraint is one reason why instructors have not included more inquiry-based investigations in their curricula. Further, the program also provides the opportunity for secondary students to participate in unique graduate student-designed activities such as experiments and field-based observations that leverage university resources, activities likely unavailable at their base schools.

In addition to core courses, FSM offers exploratory courses designed to address particularly challenging concepts or subject matter, as well as to introduce material that enriches the material typically taught in schools. These courses are often developed using suggested material from scholarly societies. For example, the evolutionary biology course, Our Evolving World, was designed using i) recommended standards from two scientific societies that identified particularly challenging evolutionary concepts and ii) peer-reviewed articles that identified widely-held misconceptions about evolution (e.g. Society for the Study of Evolution; Nadelson & Southerland, 2010; Nehm et al., 2012). We took a similar approach to curriculum design for other exploratory courses, which give students the opportunity to engage in the study of topics that are interdisplinary (e.g. brain science, forensic science) or address other special topics (e.g. astronomy, computer programming, zoology) that are typically not addressed in local schools. In many cases, material is developed de novo by those instructors with expertise in the area, adapting material from undergraduate-level introductory courses in the relevant field (see Appendix for an example from Our Evolving World). These supplementary courses have become extremely popular in recent years; for instance, in 2017 approximately 46% of all course registrations came in these courses. As reflected in student course evaluations (see below), this is likely because these courses give students opportunities to engage with unfamiliar topics and, in some cases, apply what they know from different subject areas in new contexts.

As STEM researchers, there has been an inherent interest in collecting evidence of impact since the start of FSM. In order to evaluate the rigor and success of FSM courses, we conduct short learning assessments (15-20 minutes long) at the beginning and end of our courses to measure student understanding of the key concepts in each class. We also conduct surveys with the students and instructors to collect demographic data and feedback on the effectiveness of and experiences provided by the program. We use these assessments and surveys to gauge student learning (summative) as well as to improve future iterations of the program and each course (formative). Below, we present our most recent findings and discuss their implications with respect to the strengths, limitations, and relative merits of programs like FSM, which are rare or otherwise poorly represented in the literature.

Program Demographics, Learning, Assessments, and Student Evaluations

Demographics

When students registered for FSM during the summers of 2016 and 2017, we collected demographic data on their grade level, race/ethnicity, gender, parent's educational attainment, and whether or not they received free or reduced price meals at school. Approximately 84% of the students who participated in the program were in high school (i.e. grades 9-12), with students entering the 9th, 10th, and 11th grades comprising the majority and enrolling at relatively equal rates (33.0%, 27.0%, and 18.1%, respectively; Figure 1A). Students entering the 12th grade, however, constituted only 6.3% of enrollees. Despite the FSM program being targeted primarily at high school students, middle school students (i.e. grades 6-8) made up a substantial proportion of the remaining participants in the program (15.6%), the majority of these entering the 7th and 8th grades (5.6% and 9.3%, respectively; Figure 1A). Students predominantly identified as White, not Hispanic, with approximately 35% identifying as other races/ethnicities (Figure 1B). The distribution of races/ethncities that enroll in FSM courses aligned well with the Bloomington, IN demographic data obtained in the 2010 census (United States Census Bureau, 2010), indicating that FSM attracts a representative sample of students from the local community. Further, males (50% of FSM students) and females (50%) are equally represented across the program.

ISSN:2149-8504 (online)

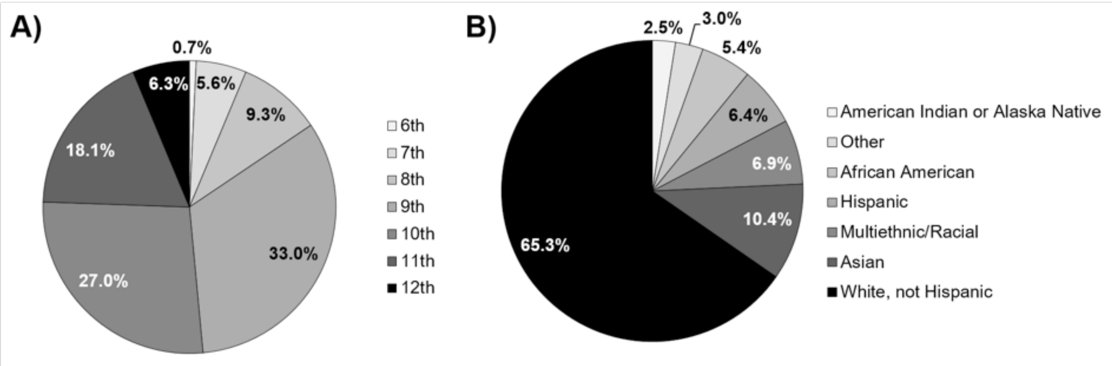

Figure 1. Demographic data on student grade level and ethnicity in summers 2016 and 2017. (A) The majority of students enrolled in FSM are preparing to enter grades 8-11 in the fall, whereas less than 15% of those enrolled will be entering grades 6, 7, and 12. **(B)** The distribution of races/ethncities that enroll in FSM courses.

While the FSM program as a whole has been very successful at attracting an equal amount of males and females (50/50 split), as well as ratios of minority students consistent with the local demographics, we observed that specific courses fail to recruit students from all backgrounds equally. For instance, less than 25% of students that enrolled in Introduction to Programming and Astrophysics for Beginners during summers 2016 and 2017 identified as female. Conversely, a disproporionately high number of female students enrolled in Brain Science, Forensic Science, and Zoology. Students who identified as African American, Native American, or Latino were underrepresented in Algebra 1, Introduction to Universe, and Astrophysics for Beginners, comprising <5% of enrollees in each. Thus, directed recruitment initiatives may be necessary to promote equitable representation across courses.

Approximately 92% of students have at least one parent with an associate's degree or higher. However, only 50% of children across the United States reside with a parent who attained a this level of education or higher (National Center for Education Statistics, 2016). Further, only 13% of the students who enrolled in FSM reported receiving free- or reduced-price meals at school, but 48% of students across the state of Indiana qualify (Indiana Youth Institute, 2018). The disproportionately low enrollment of students who do not have parents with a college degree and students who are eligible for free or reduced meal prices at school is likely due to several factors, including the fact that FSM is extensively advertised to Indiana University faculty and staff. This illuminates the need for expanded community outreach to better include households from all educational and financial backgrounds (see Raising Community Awareness below).

Learning Assessment

To assess academic improvement, we administer identical pre- and post-tests to students on the first and last (i.e. sixth) day of each course, respectively. Each course has a unique test designed to address that course's core concepts, and instructors are encouraged to incorporate content from all six class sessions into the test whenever possible. Pre- and post-test questions are composed of problems taking a variety of forms, including true or false, matching, multiple choice, and free response. Tests range from 10-15 questions and students are given 15-20 minutes for completion. Because instructors are encouraged to modify courses' syllabi as they deem necessary, pre- and post-tests for identically titled courses varied across sessions and summers. To evaluate whether students showed significant improvement between pre- and post-tests from 2011-2017, we conducted paired, two-tailed t-tests or alternatively the non-parametric Wilcoxon signed-rank test where assumptions of normality and homoscedasticity were violated (N = 8 courses total). In addition, we used an unpaired, two-tailed t-test to assess whether academic improvement differed significantly between previously (N = 18) and newly (N = 9) designed courses in 2016 and 2017. Test data from classes taught in both sessions of a given summer were combined for analysis. Sample sizes for each class ranged from 1 to 26; however, we did not analyze courses with fewer than three respondents. All analyses were conducted in SigmaPlot statistical software v. 12.5 (Systat Software, Inc.).

We found that test scores improved by 22% on average from 2011-2017, with average pre- and post-test scores of 45% and 67%, respectively. The effect size of this improvement was large, with a Cohen's D value of 2.49, indicating that the difference between the two mean test scores is greater than two standard deviations. Among science courses, we found that 32/37 (86.5%) showed statistically significant improvement. Students in mathematics showed significant improvement in 11/19 (57.9%) courses (Table 1). Among those courses that did not significantly improve, two of the science and six of the math courses were offered in 2016-2017 (see below for discussion). However, we found that there was no difference in student learning between newly (new for 2016/17) and previously established courses ($t = -0.130$, $p = 0.897$).

Overall, these results demonstrate that, during the last seven years, the FSM program has been generally successful in i) establishing courses with content that is challenging but not completely unfamiliar to students, as evidenced by the 45% average pre-test scores, which suggest some initial level of competency, and ii) that students increase their knowledge of the course material by the equivalent of two letter grades on average (i.e. 22%; $D = 2.49$). Therefore, FSM courses consistently improved student knowledge, and generally maintained this standard while adding a series of new and unique courses to its offerings. However, it is important to note that these gains are not equally distributed among course disciplines, with the number of courses demonstrating significant improvement in test scores being ~30% lower in mathematics relative to the sciences. Among the eight mathematics courses that did not show improvement during the past seven years, 75% of these were held in 2016 and 2017 (Table 1). We suggest that this may be due to two factors. First, in recent years, all mathematics courses were taught primarily by graduate students with backgrounds in mathematics, but recruited from non-mathematics departments, such as psychology and music theory. As such, they may be underprepared to teach mathematics in this type of setting (McGivney-Burelle et al., 2001; Harris et al., 2008), and in each case these courses were taught by a single instructor who lacked the benefit of feedback from a peer co-instructor. Second, we saw substantial turnover in mathematics instructors since 2015, making it difficult for instructors and their courses to improve across summer sessions and years. Recognition of these challenges led to recent structural changes in the FSM program in recruiting appropriate instructors, retaining those with experience, and providing training and peer feedback for those who are inexperienced (see below).

ISSN:2149-8504 (online)

Table 1.

Gains in student learning from 2011-2017. Included are the names of each math and science class, number of students from which pre- and post-test data were collected, the mean or median gain, and the *p*-value to indicate whether those gains were statistically significant for all years. Empty spaces indicate years in which a class was not taught or data were not collected. Dashed lines replace i) gains where only raw scores, but not percentage scores, were available, and ii) *p*-values where sample size is less than three. Overall, students significantly improved their test scores in 43 courses.

		2011			2012			2013			2014			2015			2016			2017		
		N	Gains	P	N	Gains	P	N	Gains	P	N	Gains	P	N	Gains	P	N	Gains	P	N	Gains	P
Science	Advanced Biology				8	12.9%	0.001										16	20.4%	< 0.001	8	26.1%	0.002
	Advanced Chemistry				4	-	0.036															
	Advanced Physics	3	12.0%	0.075	4	8.0%	0.165				3	22.1%	0.071									
	Astronomy										7	34.3%	0.011	6	29.8%	0.004	12	29.2%	< 0.001			
	Astrophysics																9	21.1%	0.005			
	Brain Science																			21	12.5%	0.025
	Chemistry in Food																5	35.5%	0.001	4	28.7%	0.002
	Computer Science										26	26.4%	< 0.001				8	26.3%	0.016			
	Forensic Science																			22	29.5%	< 0.001
	Introductory Biology				12	16.3%	0.001	12	-1.5%	0.535	11	16.9%	< 0.001	16	24.2%	< 0.001	11	22.8%	< 0.001	12	19.1%	0.008
	Introductory Chemistry				17	-	< 0.001							16	19.8%	< 0.001	17	26.6%	< 0.001	10	13.1%	0.057
	Introductory Physics	17	20.2%	< 0.001	18	20.6%	< 0.001	13	24.2%	< 0.001	7	22.1%	0.003	2	20.0%	-	11	30.2%	< 0.001	13	20.0%	0.004
	Introduction to Universe																			8	18.4%	< 0.001
	Our Evolving World																			6	13.3%	0.117
	Zoology																9	25.7%	0.003	6	17.0%	0.031
Mathematics	Advanced Pre-calculus				3	22.2%	0.138	2	23.6%	-												
	Algebra I																13	10.0%	0.375	14	5.7%	0.135
	Algebra II																9	31.7%	0.007	14	38.9%	< 0.001
	Calculus	6	21.7%	0.021	9	20.7%	0.021	8	24.1%	0.005	5	7.7%	0.090									
	Mathematics Problem Solving							6	32.1%	0.004												
	Pre-calculus	17	32.1%	< 0.001	16	43.2%	< 0.001	10	24.3%	0.002	4	30.2%	0.043	8	30.7%	0.006						
	Std. Test Math Review																7	11.4%	0.569	6	20.0%	0.750
	Trigonometry																6	23.4%	0.135	3	4.2%	0.789

ISSN:2149-8504 (online)

Student Course Evaluations

We distributed an exit survey alongside each post-test in the last 30 minutes of the final (i.e. sixth) class of each course. The structure of this survey was maintained across all courses, and was divided into two sections. In the first section, we asked students to evaluate their experience in the course on four criteria, including whether: i) they enjoyed the course, ii) they found the course useful, iii) they found their instructor(s) knowledgable, and iv) their overall impression of the FSM program. For each of these questions, students were asked to rank their response from 1 (lowest value) to 4 (highest value). In the second section of the survey, we asked students to identify their favorite and least favorite aspects of their course via free response. These responses were coded and binned into seven categories for both 'favorite' and 'least favorite' responses. Here, we combined responses to both questions and comments from all math (N = 14) and science (N = 29) classes conducted only during summers 2016-2017, and present student rankings from 2011-2017.

When students in the 2016-17 cohort were asked what they enjoyed most about their courses, 88 (42.7% of those who responded) said that they enjoyed the activities and laboratory-based assignments, primarily highlighting their interactive nature and utility in helping to clarify challenging concepts (Figure 2A). Further, students frequently (12.6%) listed the general subject matter of their course, as many FSM classes provide students the opportunity to learn about topics not accessible at their base school. Additionally, students listed their instructors (11.2%), the lecture content (10.7%), the amount of content in the course (8.7%), and the ability of the course to prepare them for fall classes (5.3%) as being major sources of enjoyment (Figure 2A). Conversely, when asked what they enjoyed least about their course, 26 students (23.9%) responded that they did not enjoy the topic of their course, or found the tests, surveys, homework, and lab activities to be burdensome (Figure 2B).

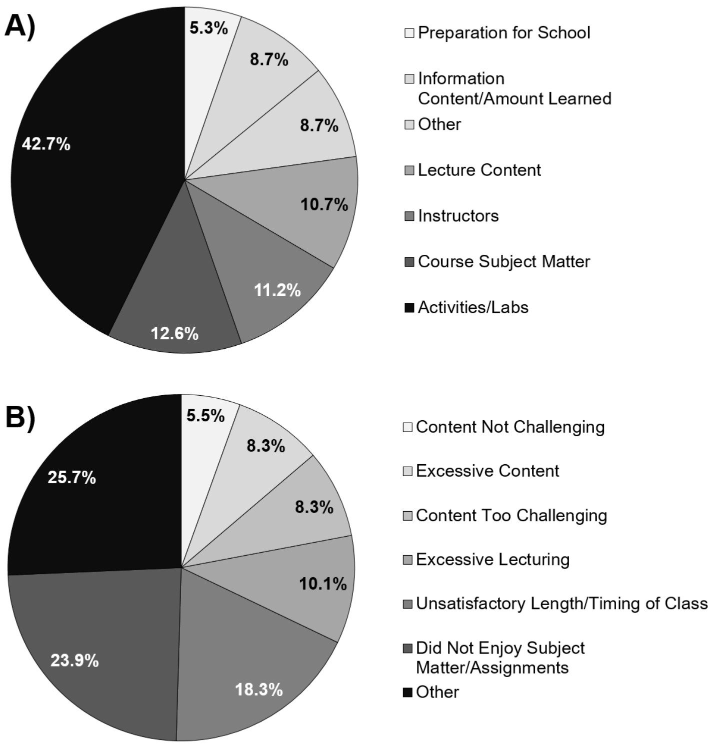

Figure 2. Student favorite and least favorite aspects of each course. (A) Students most frequently listed class activities and laboratory assignments as their favorite component of each course. **(B)** At the same time, half of all students listed their least favorite component as being i) the tests, surveys, homework, and lab activities and the subject matter, or ii) some other aspect of the course (e.g. other students, the room the course was held in, question and answer discussions)

ISSN:2149-8504 (online)

Further, a large proportion of students (18%) found the length or timing of their course unsatisfactory, primarily complaining about courses that started early (i.e. at 9am) and the two hour length of each class. Though early starting times are somewhat unpopular with students, program administrators are hesitant to change the start times, which are both necessary for FSM to offer as many courses as it does, and are preferable to many parents (Wahlstrom, 1999; Wahlstrom et al., 2014; Troxel and Wolfson, 2017). Finally, students listed excessive lecturing (10.1%) and course content (e.g. particular lecture topics; 8.3%), as well as content being either too challenging (8.3%) or not challenging enough (5.5%) as being additional sources of frustration or disappointment (Figure 2B). For all survey questions, we found that students rated FSM an average of 3.0 or higher on all survey items since 2015, with 2016 and 2017 having the highest scores since the program began in 2011 (Table 2). These results suggest that students feel positively about the program.

Table 2.

*Student assessment of FSM program from 2011-2017***.** Included are seven survey questions presented to students at the end of each FSM course. Ratings range from 1 (lowest) to 4 (highest). Dash marks indicate questions that were not asked in a particular year. No surveys were administered in 2014. With the exception of 2012 and 2013, students ranked FSM a 3 or above in all criteria each year.

	Year						
	2011	2012	2013	2014	2015	2016	2017
Did you enjoy the class?	3.14	2.92	2.87	-	3.05	3.13	3.12
Was this class useful?	3.25	2.94	2.93	-	3.16	3.21	3.18
Was the instructor prepared and knowledgeable?	3.68	3.60	3.40	-	3.58	3.53	3.48
Did the instructor communicate effectively?	3.69	3.50	3.43	-	-	-	-
Overall, how would you rate your instructor?	3.69	3.64	3.62	-	-	-	-
Overall, how would you rate this course?	3.43	3.33	3.39	-	-	-	-
Overall, what is your impression of this summer program?	3.35	3.12	3.18	-	3.26	3.33	3.38

In combination, the findings from our demographic data, learning assessments, and survey results suggest that the FSM program has and will continue to reach a substantial audience of students, that these students generally enjoy the classes they take, and that they learn a great deal within only six days of instruction. We strongly feel that the FSM model for graduate student-driven outreach and the community connections that it generates, can be readily reproduced at a wide range of higher education institutions. Below, we detail how similar programs can be initiated and maintained at other institutions, and reflect on what we learned regarding i) how to fund and maintain such a program, ii) how to recruit, retain, and train graduate student instructors, and iii) the best practices for eliciting community involvement and support for such a program.

Recommendations for Implementation at Other Institutions

Funding, Growth, and Program Maintenance

In recent iterations, FSM operated on a budget of aproximately $11,000 per year, with personnel stipends accounting for aproximately $9,500 of the budget ($250 to instructors per course taught and $250 per administrator). The remaining budget was used to purchase supplies ($1,000) and to advertise the program ($500; see below). A survey of our graduate student instructors (N = 32), however, indicates that most instructors (70%) would teach without any compensation, though fewer instructors would be willing to design a novel course (55% total). Thus, the potential exists to create and operate an FSM-like program on a budget of less than $2,000 in the event that funds are limited.

We acquire funding from several sources, including aproximately 35% of our budget from local, regional, and national granting agencies (e.g. the Indiana University Women's Philathropy Leadership Council, the Indiana Space Grant Consortium, and the Society for the Study of Evolution) as well as 35% of our budget from the Indiana University Colleges and Departments from which we recruit graduate student instructors.

The remaining 30% of our budget is funded by modest enrollment fees (these varied between $25 and $35 per course) which serve both as a source of income for the program and help to ensure attendence of the students who enroll. For instance, in the the summer of 2017, we offered free registration to the Our Evolving World course and a large number of enrollees never attended. This not only made planning difficult for the instructors but also potentially prevented enrollment of other students who would have participated if not for our limits on class size (i.e. fifteen students). Thus, should an FSM-like program be put into effect, we recommend implementing a nominal registration fee to discourage neglectful enrollments.

Recruiting, Maintaining, and Training Graduate Student Instructors

Graduate student instructor recruitment is one of the most important duties in maintaing the FSM program. These efforts are driven primarily through a call-out meeting advertised to all relevant departments at the beginning of each academic year, though often times positive word-of-mouth leads potential instructors to contact program administrators directly. The graduate student instructors are paid a small stipend ($250), but potential instructors are often driven by opportunities to develop curricula, direct education research, participate in grant-writing, gain administrative experience, and take advantage of in-class teaching opportunities that might otherwise be unavailable in a traditional graduate education (Davis and Kring, 2001; Cherrstrom et al., 2017). As a result of its popularity, FSM administrators have, at times, had to turn away ambitious graduate students due to an overabundance of instructors, particularly in the natural sciences (see more below).

Although the FSM program was met with enthusiasm by the graduate student community, it has been difficult to recruit instructors from some academic departments, such as Computer Science and Mathematics. Other departments, such as Biology, have long had larger pools of willing graduate-student participants than instructor vacancies. We suspect that some of this disparity is due to different summer research expectations and demands by these departments, the importance of participating in external private internships during the summer, as well as the availability of summer funding, for which the modest FSM instructor stipend makes only a small contribution. However, while for most disciplines it is rarely challenging to find available and qualified graduate students, perhaps the greatest obstacle for the continuation and growth of FSM has been the regular turnover of talented instructors, which appears to be driven primarily by instructor obligations in their research laboratories and other academic conflicts. For instance, in summer 2017, 75% of all instructors were new to the FSM program, and only 60% of instructors indicated that they would participate in the next summer. Among those who would not be participating, 80% indicated that they would be graduating, preparing for preliminary examinations or expected a scheduling conflict. Although turnover is high in the FSM program, this is not due to a lack of incentive to participate or instructor dissatisfaction with their experience.

For the first five years of the FSM program, instructors received no direct training or feedback from program administrators or peers within their academic discipline, with feedback derived solely from student course evaluations. However, instructors at Indiana University have benefitted from graduate-level coursework in research-based teaching methods offered at the university, including a class offered by one of the authors (Maltese) entitled University STEM Teaching. This model of allowing graduate students to develop their own curricula, manage their classrooms, and make adjustments where appropriate has long been highlighted as a major factor in recruiting graduate students to the FSM program. Indeed, as of 2017, 90% of FSM instructors feel that participation in FSM improved their teaching skills, and 70% indicated a greater interest in pedagogy and teaching due to their participation in the program. The low improvement scores in a subset of recent mathematics courses, however, makes it clear that some instructors are likely poorly prepared to design or independently instruct a course. Whether this is due to high instructor turnover or the increasing demands on mathematics instructors that came with the rapid growth of FSM is not clear. In an attempt to remedy this situation, FSM instituted a policy in 2017 mandating meetings with all instructors in science and exploratory courses in order to modify and improve both longstanding and novel courses through peer review prior to the beginning of each summer session. These interventions likely explain the initial success of the newly designed courses and are now being applied to the mathematics program. In addition, where instructors are available, we attempted to assign two instructors to each classroom and pair less experienced instructors with more

ISSN:2149-8504 (online)

experienced peers (i.e. 1+ year of program experience). Finally, Indiana University has a number of programs in place, such as pedagogy courses, the Center for Innovative Teaching and Learning, and other training opportunities where FSM instructors can learn strategies and invite those with expertise to observe and critique their courses and curricula.

Raising Community Awareness

Among the various tasks involved in maintaining and growing the FSM program, perhaps the most time-intensive has been raising community awareness through graduate student-led outreach. These efforts span an approximately seven-month period (i.e. December – June), and taken a variety of formats, ranging from designing and hanging flyers, outreach at local venues (e.g. science fairs, museums, farmers' markets), and digital correspondence (e.g. via e-mail, social media).

Efforts to advertise the FSM program begin in earnest each December with the designing of the annual flyer, detailing the courses offered, prices, time and location of the program. By February, program administrators begin posting these flyers throughout the community, including local businesses, churches, the county and campus libraries, heavily trafficked parts of our university campus, and museums. By March and April, e-mails advertising the program are sent to parents of past FSM students as well as university faculty and staff. In parallel, schools are contacted with a request that flyers be placed in hallways and classrooms by school staff, and this is followed-up with individualized e-mails to all math and science teachers, as well as guidance counselors at these schools. In combination, these efforts yielded approximately 25% of all 2017 registrations (see Figure 3 for additional sources of registration). Throughout this time period, we use digital advertising to reach potential FSM parents and students. Specifically, we post our flyer on an online bulletin board maintained by the local community school corporation, and use outreach funds to post paid advertisements to social media websites (yielding ~18% of all registrations; Figure 3).

In May, approximately one month prior to the beginning of classes, we attempt to more directly interface with the community by holding informational meetings about the program, while also performing scientific demonstrations and passing out flyers at the community farmers' market. These sustained and thus far highly successful outreach efforts required a great commitment of time and energy from FSM administrators and course instructors, who are generally enthusiastic about participating. Indeed, when asked if they would be willing to contribute to program outreach in the next year, 72% of instructors indicated that they would be 'somewhat' to 'extremely' interested in participating.

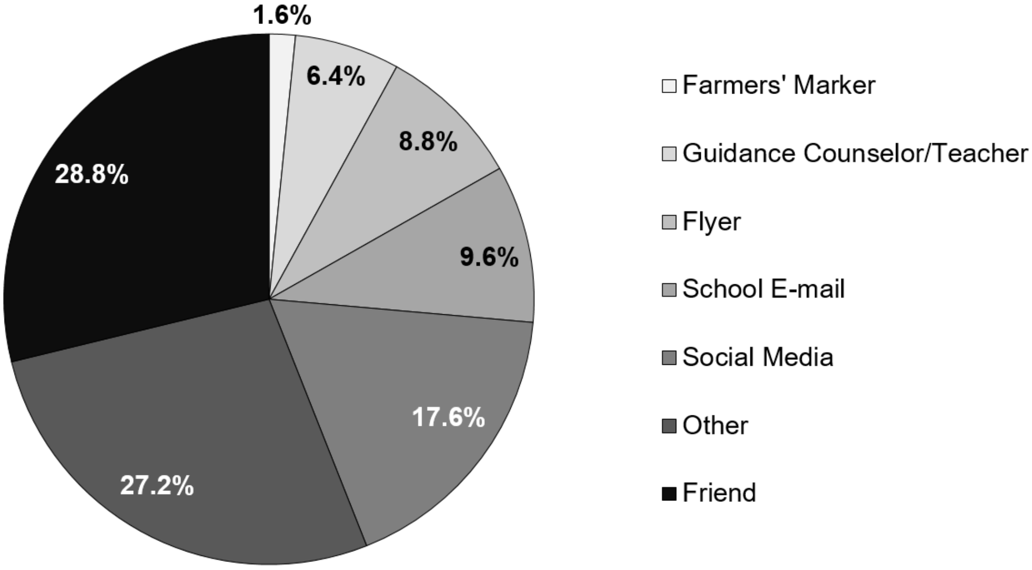

Figure 3. *How students and parents hear about the FSM program*. More than half of all parents and students hear about FSM through friends or other sources (e.g. web search, IU website), whereas the other half hear about the program through social media, e-mails from the school, flyers, guidance counselors/teachers, or the farmers' market.

ISSN:2149-8504 (online)

One of the longstanding goals of the FSM program is to provide greater access to this program for traditionally underserved and disadvantaged groups. To do so, we began to take a more targeted outreach approach by partnering with community groups. Specifically, we are offering pre-enrollment and fee remissions to members of local youth organizations focused on supporting girls, minorities, and low income families, such as the Girl Scouts, Girls Inc., and the Boys and Girls Club. We hope that by directly advertising to these groups and decreasing the financial burden of participating in our program for those that need it, we can increase the exposure of our program within the community and better serve students from all backgrounds.

Conclusions and Future Directions

Across seven years of growth and development, the Foundations in Science and Mathematics program has continually sought to provide a mutually beneficial setting in which secondary students can explore scientific and mathematical concepts in a collaborative, active learning envronment, and graduate students can develop their pedagogical, administrative, and science communication skills (Tanner and Allen, 2006). Based on quantitative assessments of student learning, as well as student and instructor course evaluations, it is now clear that this program is achieving these goals, and in so doing promoted collaboration between IU and local educational institutions and community organizations. These achievements have likely come as a result of successful funding strategies, effective management and the development of substantial program infrastructure, as well as a reliance on active learning strategies (Prince, 2004; Freeman et al., 2014), all of which are the product of graduate student efforts since 2011.

At the same time, we identified several challenges associated with maintaining a program such as FSM, including the need to train and retain talented graduate students, to collaboratively revise curricula to incorporate active learning that can better foster student learning (Freeman et al., 2014; Schwartz et al., 2016), and to more effectively perform outreach to disadvantaged communities. At the same time, although taking an active learning approach has been successful, we hope to incorporate inquiry-based approaches that span the duration of each course, as individual two hour classes make this approach difficult to incorporate. Despite these challenges, we feel that FSM has great potential for future growth, and believe strongly that expanding this model to additional colleges and universities holds great promise for reaching larger and more diverse communities of young learners and future STEM professionals (Kitchen et al., 2018). We therefore urge interested parties to contact us through our website (i.e. http://www.indiana.edu/~fsm/) or via e-mail (fsm@indiana.edu) in order to explore this possibility.

Acknowledgements

We thank Teddie Phillippson-Mower and staff in the Office of Science Outreach, the Physics Department, and IU Conferences for providing the substantial administrative support that enabled this program to grow and diversify. We also thank William R. Shoemaker for allowing us to include his activity in the Appendix. Funding was provided by the Indiana Space Grant Consortium Grant 4103-82095, the Indiana University Women's Philanthropy Leadership Council 2017 Grant, and the Society for the Study of Evolution Small Grants Program.

ISSN:2149-8504 (online)

References

Allen, A., & Chavkin, N. F. (2004). New evidence that tutoring with community volunteers can help middle school students improve their academic achievement. *School Community Journal*, *14*(2), 7.

Bennett, J., Fry, J., Timme, N., & Maltese, A. (2012). Lessons learned from a summer preparatory program on foundations in physics and calculus. *Journal of College Science Teaching*, *41*(4), 52.

Cherrstrom, C. A., Richardson, R., Fowler, D., Autenrieth, R., & Zoran, M. J. (2017). Creating Teaching Opportunities for STEM Future Faculty Development. *Journal of STEM Teacher Education*, *52*(1), 55-69.

Cook, P. J., Dodge, K., Farkas, G., Fryer, R. G., Guryan, J., Ludwig, J., & Mayer, S. (2015). Not Too Late: Improving Academic Outcomes for Disadvantaged Youth. Institute for Policy Research Northwestern University Working Paper WP-15-01. http://www. ipr. northwestern. edu/publications/papers/2015/ipr-wp-15-01. html.

Davis, S. F., & Kring, J. (2001). A model for training and evaluating graduate student teaching assistants. *College Student Journal*, *35*(1), 45-51.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410-8415.

Harris, G., Froman, J., & Surles, J. (2008). The professional development of graduate mathematics teaching assistants. *International Journal of Mathematical Education in Science and Technology*, *40*(1), 157-172.

Indiana Youth Institute (2018). 2018 Indiana KIDS COUNT® Data Book: A profile of Child Well-Being. Retrieved from https://s3.amazonaws.com/iyi-website/data-book/2018-Indiana-KIDS-COUNT-Data-Book.pdf

Kim, K. S., Rackus, D. G., Mabury, S. A., Morra, B., & Dicks, A. P. (2017). The Chemistry Teaching Fellowship Program: Developing Curricula and Graduate Student Professionalism. *Journal of Chemical Education*, *94*(4), 439-444.

Kitchen, J. A., Sonnert, G., & Sadler, P. M. (2018). The impact of college-and university-run high school summer programs on students' end of high school STEM career aspirations. *Science Education*.

Laursen, S., Liston, C., Thiry, H., & Graf, J. (2007). What good is a scientist in the classroom? Participant outcomes and program design features for a short-duration science outreach intervention in K–12 classrooms. *CBE-Life Sciences Education*, *6*(1), 49-64.

McGivney-Burelle, J., DeFranco, T. C., Vinsonhaler, C. I., & Santucci, K. B. (2001). Building Bridges: Improving the Teaching Practices of TAs in the Mathematics Department. *Journal of Graduate Teaching Assistant Development*, 8(2), 55-61.

Nadelson, L. S., & Southerland, S. A. (2010). Examining the interaction of acceptance and understanding: How does the relationship change with a focus on macroevolution?. *Evolution: Education and Outreach*, *3*(1), 82-88.

National Center for Education Statistics (2016). *Number and percentage distribution of children under age 18, by parents' highest level of educational attainment, child's age group and race/ethnicity, and household type: 2010 and 2016*. Retrieved from https://nces.ed.gov/programs/digest/d17/tables/dt17_104.70.asp?current=yes.

Nehm, R. H., Beggrow, E. P., Opfer, J. E., & Ha, M. (2012). Reasoning about natural selection: diagnosing contextual competency using the ACORNS instrument. *The American Biology Teacher*, *74*(2), 92-98.

Parker, M. A., Ashe, D., Boersma, J., Hicks, R., & Bennett, V. (2015). Good Teaching Starts Here: Applied Learning at the Graduate Teaching Assistant Institute. *The Canadian Journal of Higher Education*, *45*(3), 84.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, *93*(3), 223-231.

ISSN:2149-8504 (online)

Reeves, T. D., Hake, L. E., Chen, X., Frederick, J., Rudenga, K., Ludlow, L. H., & O'Connor, C. M. (2018). Divergent Findings in the Cross-Institutional Evaluation of Graduate Teaching Assistant Professional Development Programs. *CBE-Life Sciences Education*, *17*(8), 1-13.

Schwartz, D. L., Tsang, J. M., & Blair, K. P. (2016). *The ABCs of how we learn: 26 scientifically proven approaches, how they work, and when to use them*. WW Norton & Company.

Tanner, K. D., & Allen, D. (2006). Approaches to biology teaching and learning: On integrating pedagogical training into the graduate experiences of future science faculty. *Cell Biology Education*, *5*, 1-6.

Timme, N., Baird, M., Bennett, J., Fry, J., Garrison, L., & Maltese, A. (2013). A summer math and physics program for high school students: Student performance and lessons learned in the second year. *The Physics Teacher*, *51*(5), 280-284.

Troxel, W. M., & Wolfson, A. R. (2017). The intersection between sleep science and policy: introduction to the special issue on school start times. *Sleep Health: Journal of the National Sleep Foundation*, *3*(6), 419-422.

Ufnar, J. A., Bolger, M., & Shepherd, V. L. (2017). A retrospective study of a scientist in the classroom partnership program. *Journal of Higher Education Outreach and Engagement*, *21*(3), 69-96.

United States Census Bureau (2010). *Profile of General Population and Housing Characteristics: 2010*. Retrieved from https://factfinder.census.gov/bkmk/table/1.0/en/DEC/10_DP/DPDP1/1600000US1805860.

Wahlstrom, K. L. 1999. The prickly politics of school starting times. *Kappan*, *80*(5), 344-347.

Wahlstrom, K. L., Dretzke, B., Gordon, M. Peterson, K., Edwards, K., & Gdula, J. (2014). *Examining the Impact of Later School Start Times on the Health and Academic Performance of High School Students: A Multi-Site Study*. Center for Applied Research and Educational Improvement. St. Paul, MN: University of Minnesota.

ISSN:2149-8504 (online)

Journal of Research in STEM Education

Vol 4, No 2, December 2018, 130-145

RESEARCH REPORT

What Does an Engineer Do? Conceptual Changes and Effects of Fellow Engagement on Middle School Students Involved in a GK-12 Program

Vincent R. Genareo[a1], Mari Kemis[b], D. Raj Raman[b]

[a]*Salisbury University, USA;* [b]*Iowa State University, USA*

Abstract: *This study investigates students' conceptions of engineering at the beginning and end of their involvement in a National Science Foundation funded Graduate STEM Fellows in K-12 Education (GK-12) program. It examines whether students involved in the program exhibited greater conceptions of engineering from beginning to end, whether differences exist among males and females, and if students' engagement and satisfaction with their Fellows affects growth in conceptions of engineering. Pre-survey and post-survey data were collected annually over four years from 1,522 participants in grades 7 and 8 who had a GK-12 Fellow. Statistical analyses indicated students gained significantly in their conceptions of engineering during a year of GK-12 involvement. Those with a second year benefitted more, and the initial conception of engineering gap that occurred between males and females was closed by the end of students' involvement in GK-12. The greater the degree of student engagement and satisfaction with their GK-12 Fellows, the more accurate were their conceptions of engineering. This study suggests STEM-focused partnership programs may positively affect students' career conceptions, and there is value in value placing resident scientists who can facilitate student engagement in classrooms. Recommendations to program coordinators are provided.*

Keywords: STEM partnerships, middle school, conceptions of engineering

Introduction

One In 1999, the National Science Foundation (NSF) launched the Graduate STEM Fellows in K-12 in Education (GK-12) program that paired Ph.D.-level graduate students (Fellows) with K-12 classroom teachers. Although the focus of these programs varied by institution, they generally followed one of two models (Mitchell et al., 2003). The "exposition model" provided Fellows with opportunities in schools to present to students and teachers in a limited capacity, while the "classroom immersion model" paired Fellows with one or more K-12 teachers in the classroom throughout a school year. Most GK-12 programs used the latter approach, and it was the model employed for this study.

Multiple investigators demonstrated the validity of using an analysis of drawing and writing samples to evaluate student conceptions of engineering (Capobianco, Diefes-Dux, Mena, & Weller, 2011; Knight & Cunningham, 2004). Some studies have focused on the impact of GK-12 programs (in particular) on students' perceptions of and attitudes toward engineering, finding students make gains in their conceptions of engineering, or develop more positive attitudes about engineering disciplines, as a result of having a scientist in their classroom (Lyons, 2011; Thompson & Lyons, 2008). However, little research has examined gender differences in gains in conceptions of engineering, and no research has examined the relationships between student engagement and satisfaction with their GK-12 Fellows and increases in conceptions of engineering.

[1] Corresponding Author. Salisbury University, 1101 Camden Avenue, CH 281D Salisbury, MD 21801 Email: vrgenareo@salisbury.edu

Genareo, V. R., Kemis, M., & Raman, D. R. (2018). What Does an Engineer Do? Conceptual Changes and Effects of Fellow Engagement on Middle School Students Involved in a GK-12 Program. *Journal of Research in STEM Education*, *4*(2), 130-145.

ISSN:2149-8504 (online)

Literature Review

This research is grounded in the conceptual change model as proposed by Vosniadou (1994). This conceptual change model examines the nature of scientific conceptual change in children. In Vosniadou's model, students' concept acquisition are best supported when they actively engage in their learning, ask and answer questions, and are involved in a dialogue with teachers (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001). Students create mental models that allow them to understand and explain complex processes and theories. Students may change their conceptual understanding either through enrichment of existing conceptual models (adding to what they already know) or through revision of their conceptual models (changing what they believe). Inconsistencies in students' presuppositions, which underpin their mental models, create misconceptions. Misconceptions may be difficult to overcome, and often take active teaching processes to help students engage with material, question their presuppositions, and revise their conceptual models. Simply, conceptual revisions can occur through careful structuring of students' experiences (Vosniadou, 2007).

Numerous studies have examined students' conceptions and misconceptions of engineering. Previous research confirmed that elementary and middle school students hold misconceptions about the engineering field (Hammack & High, 2014). Many of these students believe engineers perform mechanical work, fix vehicles, or drive trains (Fralick, Kearn, Thompson, & Lyons, 2009; Cunningham, Lachapelle, & Lindgren-Streicher, 2005). Typically, these studies use the Draw An Engineer Test (DAET), allowing students to draw and briefly explain the job of an engineer (Yap, Ebert, & Lyons, 2003; Knight & Cunningham, 2004).

Students in middle school begin to develop potential career aspirations, and stereotypes or misconceptions about the science fields can potentially cause students to avoid pursuing these careers (McDuffie, 2001). Studies of conceptions of engineering found that elementary and middle school students believe science and engineering are largely male-oriented fields (Fralick et al., 2009; Capobianco et al., 2011). The generally masculine conceptions of engineering can influence females' academic performance and career selection in those areas (Kelley & Bryan, 2018). Students are more likely to select occupations when they accurately understand the field and have the self-confidence and self-efficacy to believe they can be successful (Komarraju, Swanson, & Nadler, 2014).

To help develop middle school students' interest and confidence in engineering, most teachers need professional development to improve their pedagogical content knowledge and inquiry-based instructional strategies, and universities and engineering experts should provide outreach to schools to provide authentic and meaningful science, technology, engineering, and mathematics (STEM) experiences (Page, Lewis, Autenrieth, & Butler-Purry, 2013; Rockland, Bloom, Carpinelli, Burr-Alexander, Hirsch, & Kimmell, 2010). Unfortunately, Cantrell and Robinson (2002) found middle school and secondary science textbooks have historically provided classroom teachers with ineffective engineering activities and often fail to make concrete connections to math and science content. Although the GK-12 program had been shown to be a successful model for increasing student awareness of engineering fields (Lyons, 2011) and interest in engineering careers (DeGrazia, Sullivan, Carlson, & Carlson, 2001), recent research called into question the effectiveness of the GK-12 program's long-term impact on students' interest and confidence in STEM careers. Genareo, Mitchell, Geisinger, and Kemis (2016) found that students lost interest and confidence in all four STEM areas between their middle school GK-12 involvement and the end of high school.

There is also a push to attract more students in STEM fields, particularly minority students and females (National Academy of Engineering, 2008). As of 2014, females accounted for only 15.2% of tenured and tenure-track faculty, and African Americans receiving a bachelor's degree in engineering had been on a consistently downward trend since 2005 (Yoder, 2014). Two of the goals of the GK-12 program were to "connect elementary and secondary learning to the habits and skills required for future study in STEM disciplines [and] provide role models for future STEM professionals" (Mitchell et al., 2003, p. 4). This study examined the GK-12 program's success in changing students' conceptions of engineering, and potential reasons for variations.

ISSN:2149-8504 (online)

Significance of the Study

The American public has a poor understanding of what engineers do (Davis & Gibbons, 2002), and many teachers have even developed misconceptions about the engineering field (Cunningham et al., 2005). Some students may feel they are not smart enough to be engineers, or see it as an isolated and sedentary lifestyle that does not appeal to them (National Academy of Engineering, 2008). Misconceptions about engineering careers may contribute to fewer females in engineering fields (Tonso, 2006). Even as the number of female engineering students has increased over the last decade, as of 2015, woman accounted for only 21% of bachelor's degrees, 23% of master's degrees, and 25% of doctoral degrees in engineering (Banerjee, 2015).

With an inadequate understanding of engineering, students are unlikely to select an engineering career (Hirsch, Carpinelli, Kimmell, Rockland, & Bloom, 2007). Research in closely related fields, such as science, found that classroom interventions addressing students' misconceptions of scientists could help clarify their ideas about science careers (Finson, 2002). In relation, it is important to understand what beliefs students have developed about the engineering profession. While conceptions of engineering may be only one factor in these students' career decision-making, there is evidence that students are more likely to choose careers they understand, and in which they have role models (Lent, Brown, & Hackett, 2002).

Middle school is a critical period for students in developing their interests in STEM fields, and it is vital that students are exposed to and develop STEM interests prior to high school (Mohr-Schroeder et al, 2014; Tafoya, Nguyen, Skokan, & Moskal, 2005). Therefore, to add to existing literature on students' conceptions of engineering (Fralick et al., 2009), and to address the call for research of middle school intervention programs on student STEM career perceptions (Knezek, Christensen, Tyler-Wood, & Periathiruvadi, 2013), this study examines: (1) magnitude and types of change in conceptions of engineering that occur as a result of middle school students' involvement in a school-university STEM partnership, specifically, their long-term exposure to a Fellow, (2) differences in gains between males and females, and (3) the generally unexplored research into levels of students' engagement and satisfaction with their Fellows and its correlation to gains in conceptions of engineering.

In this study, we examined middle school students' conceptions of engineering using pre-survey and post-survey data administered to all students in classrooms with a GK-12 Fellow. Students completed a pre-survey within one to two weeks of the beginning of the school year and then a post-survey during the last month of the school year. Data were collected during four academic years. The findings describe students' gains in their conceptions of engineering; differences in gains between male and female students; gains of students who were in the program for a second year; and how their levels of engagement and satisfaction contribute to their gains in conceptions of engineering. Recommendations for program coordinators and researchers are then offered to aid in developing programs that may contribute to even greater student understanding of engineers and engineering.

Research Questions

Three research questions guided this study: (1) Do students involved in a GK-12 program develop significant changes in their conceptions of engineering? (2) Do males and females have different gains in their conceptions of engineering? (3) Does a higher level of student engagement and satisfaction with the GK-12 Fellow affect their change in conceptions of engineering?

GK-12 Program Description

The GK-12 program in this study was a five-year joint partnership between a university, a public school district, and the National Science Foundation (Award # DGE – 1007911), using a classroom immersion model. Prior to the school year, the Fellows received 50 hours of professional development in pedagogy, realities of working in a middle school classroom, how to use technology in the classroom, and strategies for communicating science concepts to middle school students. During the school year, the Fellows and teachers worked together to prepare lessons and teaching activities. The Fellows were in the classroom one day a week, typically employing inquiry-based instructional methods. The objectives of the program were to: 1) provide

ISSN:2149-8504 (online)

Fellows with a graduate experience that prepared them for interdisciplinary research; 2) to train Fellows to become outstanding teachers and better communicators; 3) to provide professional development opportunities for middle school educators; and 4) to engage middle school students in scientifically-oriented questions and problem-based learning, intending to result in increased student interest in STEM fields.

The GK-12 Fellows were Ph.D. students in a variety of science programs at a large, Midwestern university. They sought advanced degrees in subjects including Agronomy; Biophysics and Molecular Biology; Chemical and Biological Engineering; Chemistry; Ecology, Evolution, and Organismal Biology; Materials and Science Engineering; Electrical and Computer Engineering; Genetics, Development, and Cell Biology; Natural Resource and Ecology Management; and Organic Chemistry. Six Fellows were selected during Year 1, nine during Year 2, 10 during Year 3, and nine during Year 4. Nine Fellows remained in the GK-12 program for two years. Table 1 lists the number, the program of study, gender, and racial/ethnic background of the Fellows during each of the four program years.

Table 1.
Fellow Demographics by Program Year

Program Year	New Fellows (*n*)	Returning Fellows (*n*)	Total Fellows (*N*)	Program of Study: Engineering (*n*)	Program of Study: Other Science (*n*)	Fellow Gender	Fellows' Racial/Ethnic Background
1	6	-	6	0	6	3 F, 3 M	5 Caucasian, 1 African American
2	7	2	9	0	9	2 F, 7 M	8 Caucasian, 1 African American
3	5	5	10	2	8	0 F, 10 M	10 Caucasian
4	7	2	9	2	7	2 F, 7 M	9 Caucasian

GK-12 Classroom Activities and Pedagogy

In the classrooms, the Fellows worked with their partner classroom teachers to design engaging curriculum for the middle school students. Results of evaluation reports (collected annually by our research institute through surveys and focus groups with all participating Fellows and teachers) indicate that much of the teaching was grounded in student inquiry and project-based learning (both of which were taught to Fellows during their professional development prior to the school year). Students engaged in activities such as: flight simulators, chromatography labs, DNA extraction, and metabolism measurement of snakes. A small selection of project examples included creating: musical instruments, biodiesel, computer-coded applications, soap, robots, and genetically-modified plants. They engaged in measuring energy consumption of electronic products, designed Rube Goldberg machines to understand energy transfer, and built audio speakers. In reviewing their learning activities, it is difficult in most cases to determine whether these activities fall into categories of science or engineering. One engineering Fellow, for example, worked with the students to learn about viscoelastic materials (his dissertation research topic) to understand how forces affect polymers differently than other materials. Many such activities included concepts often considered elements of both engineering and science.

Methodology

Participants

Schools. Students in six schools participated in this study. All six schools were located in a large, urban school district, with a community population of approximately 200,000, and served students in grades six through eight. They all had a generally diverse student body. Table 2 lists school demographic information, including enrollment, percentage of free/reduced lunch eligible students, and percentage of students of diverse backgrounds.

ISSN:2149-8504 (online)

Table 2.
Participating School Demographics

School	Approximate Enrollment	Free/Reduced Lunch Eligible (%)	Students of Diverse Backgrounds (%)
A	750	58.0	36.1
B	650	72.9	51.4
C	720	76.2	63.8
D	700	93.9	74.2
E	490	85.2	44.3
F	630	97.6	85.7

Students. A total of 1,522 students in seventh and eighth grade participated in this study. Fifty-one percent of participating students were female. Approximately 51% were in seventh grade and 49% were in eight grade, and about 49% were students of diverse racial or ethnic backgrounds. Table 3 lists the student participant demographic information.

Table 3.
Student Demographic Information by Program Year

Year	Schools (from Table 1)	Grade 7 (*n*)	Grade 8 (*n*)	Year Total (*n*)	Female Students (*n*)	Male Students (*n*)	Students of Diverse Backgrounds (*n*)
1	A, B, C, D, F	127	194	321	153	167	148
2	A, B, C, D, E, F	210	178	388	201	183	189
3	A, B, C, D, E	237	194	431	223	200	213
4	A, B, C, D, E	203	179	382	194	183	190
Total		777	745	1522	771	733	740

Note: 18 students did not provide their gender.

Survey

Students with a GK-12 Fellow completed a pre-survey in August and a post-survey in April. These surveys measured students' attitudes, perceptions, and confidence in STEM areas, including engineering. At both administrations, an open-ended item on the survey asked them to respond to the question, "What does an engineer do?" To determine the level of students' conceptions of engineering, a coding system was developed to quantify conceptual levels of students' responses. Additionally, five survey items asked students to rate, on a Likert-type scale, their level of agreement with: (1) I like talking to our Fellow; (2) Our Fellow makes learning more interesting; (3) I like having a Fellow in our classroom; (4) I am more interested in studying science because we had a Fellow in our classroom; and (5) Our Fellow helps us understand what we're learning in class. The Fellow administered the survey during regular class time.

Coding Rubric Development

Traditionally, conceptions of engineering have been measured using the Draw-an-Engineer Test (DAET) (Yap, Ebert, & Lyons, 2003), which is a modified version of the Draw-a-Scientist Test (Chambers, 1983). Students' drawings and small writing samples are coded to determine what students believed engineers look like and do. Typically, responses are presented descriptively and without levels of greater understanding, although it is generally understood that a "low level" of conception involves beliefs that engineers build things, fix things, or drive trains or cars (Knight & Cunningham, 2004). Updated scoring guidelines for the DAET allow for conceptual levels (from 0-3) that indicate levels of conceptions of engineering (Thompson & Lyons, 2008). Using these scoring levels as a guide, the coding rubric, with codes from 0-4, was developed and further refined during the coding process (see Appendix A for the coding rubric).

ISSN:2149-8504 (online)

The rubric was anchored by codes of 0-2, indicating misconceptions or elementary understanding of engineers, and 3-4 that indicated a more sophisticated conceptions of engineering. Lower coded responses (coded 0-2) indicated misconceptions or elementary understanding of engineers. For example, if a student wrote a response with no content (e.g., "I don't know), the response was coded as a zero. If a student's response displayed a common misconception (e.g., "Engineers work in hospitals taking care of the sick"), or equated an engineer to an automobile mechanic or train operator, a common misconception among young people (Knight & Cunningham, 2004), the response was coded as a one.

Responses coded as a two included an example of work engineers perform or the items they work with, referred to as engineering products (Oware, Capobianco, & Diefes-Dux, 2007). If students provided one engineering product (e.g., "Engineers make bridges"), wrote that engineers build or fix things, or provided vague responses (e.g., "Math and science"), their response was coded as a two. These responses are higher-level, but if students believe engineers only build or fix things, it can be a sign of an incomplete understanding of the career, or potential misconceptions (Fralick et al., 2009).

Higher coded responses (coded 3- 4) indicated a more sophisticated conceptions of engineering. Items coded as a three represented more complex understanding of engineers, because they either offered multiple engineering products (e.g., "They can make things like computers, bridges, etc.") or included a function of engineering (e.g., "managing, teaching, testing") that is not typically represented in conceptions of engineering research (Eide, Jenison, Northup, & Mickelson, 2012). The highest level of conceptions of engineering was coded as a four. These responses could have included multiple functions of engineers (e.g., "Engineers design and invent…"), engineering as a means of social or organizational improvement (e.g., "Engineers help society by…"), or combined code levels two and three in some fashion (e.g., "Use science and math to design medical instruments").

Rubric validity. The rubric was developed in collaboration between staff in a research institute with expertise in assessment and a full professor of engineering. The rubric was created through alignment of elements in undergraduate engineering textbooks, supporting its face validity. To determine content validity, the rubric was sent to two university assistant professors in engineering fields and one assessment specialist, who examined the content of each rubric level. They were supplied with a copy of the rubric, and, using the Lawshe approach (Gilbert & Prion, 2016), were asked to rate whether the content of each coding level represented content that was Essential, Useful but Not Necessary, or Not Essential to measuring students' conceptions of engineering. The Content Validity Index (CVI) value for the rubric was .99, meaning the three experts rated each of the rubric items as being essential to measuring the intended content of the rubric.

Rubric coding reliability. One researcher used the rubric to code all responses for conceptions of engineering. A second researcher coded a reduced sample of student responses. Cohen's Kappa determined if there was inter-rater reliability between the two scorers' codes (Table 4). Percentage of agreement was also computed to report the percentage of matched coding. An agreement of 85% is generally acceptable (Leedy, 1997).

Table 4.
Coding Reliability

	Coded Cases for Reliability (*n*)	% of Total Cases	% Coder Agreement	*k*	Agreement Classification[a]	*p*
Engineer Conception						
pre	1109	72.9	88.3	.832	Almost perfect	<.0005
post	1014	66.6	86.8	.712	Substantial	<.0005

Note. [a]Terms as described in Landis & Koch, 1977

ISSN:2149-8504 (online)

After examining scoring reliability and agreement, coding differences were discussed, agreed on, and recoded if necessary. Finally, the coding rubric was refined to better clarify the categories.

Item factor analysis. A factor analysis, using a Varimax rotation, tested the factorability of the five, Likert-type survey items. The completed student responses were tested with a Principle Components Analysis to analyze item variance, resulting in a Kaiser-Meyer-Olkin measure sampling adequacy of .885, $p < .001$, well above traditional recommended value of .60. This confirmed that each item shared common variance with the other items, or that all items factored into a common construct, which was termed student engagement and satisfaction.

Data Analysis

A paired-samples t-test determined if gains in conceptions of engineering were significant for all years combined. An independent samples t-test examined significance in gains between males and females. Results were reported as means of beginning and end conceptions of engineering, gains, and potential significance for all responses overall, as well as for males and females. For students involved in the GK-12 program a second year, a repeated measures Analysis of Variance (ANOVA) provided significance of conception of engineer mean gains from the beginning of the first year to the end of the first and second years. Matched student responses were selected to demonstrate the types of gains students made in their responses at each growth level (0 - 4). By recoding variables by student response levels, independent samples t-tests showed the significance of gains students made in their conceptions of engineering at each level of agreement (strongly disagree to strongly agree) on five survey items representing students' levels of engagement and satisfaction with their fellows.

Results

The following section provides the results of the investigation of the study's three research questions. The gains in conceptions of engineering by student gender and overall student sample are presented. Next, students' gains by self-reported engagement and satisfaction with the Fellow are reported. Finally, results of overall growth, and by gender, for students who had a second year of GK-12 involvement are presented.

Changes in Conceptions of Engineering

During the four project years, the total gains in students' conceptions of engineering as measured by the rubric (0-4) prior to their involvement in the GK-12 program to the end of their academic year of involvement were significant, $t(1521) = 12.28$, $p < .001$ (Table 5). Students exhibited a mean gain of .43. Additional analysis by each project year had similar results (not tabled). Overall, students involved in the GK-12 program made significant gains in their conceptions of engineering after one year of participation, progressing from a level of misconceptions or simplistic understanding ($m = 1.84$) to a level of understanding the varied or multiple roles of engineers ($m = 2.27$). It is important to note that analyses were run by the Fellows' program (i.e., differences in student gains whether they had Fellows who were scientists and engineers), and no statistical differences occurred because of Fellows' program.

Table 5.
Gains in Conceptions of Engineering

	Prior to Program			After Program				
	n	*M*	*SD*	*n*	*M*	*SD*	Mean Gain	*t*
Total	1522	1.84	1.11	1522	2.27	1.14	.43	12.28**
Grade 7	777	1.85	1.17	777	2.27	1.18	.42	8.41**
Grade 8	745	1.83	1.04	745	2.27	1.11	.44	8.97**

Note: * $p < .05$, ** $p< .001$

ISSN:2149-8504 (online)

Example responses by levels of student gain. The following student responses demonstrate levels of gains students made through the school year. These were chosen for the purpose of illustrating the levels of engineering conceptual growth (Table 6).

Table 6.

The levels of engineering conceptual growth.

Growth (pre/post)	Prior to Program	Level	After Program	Level
0 Points	Fix things.	2	They work on stuff like cars.	2
1 Point	Building stuff.	2	An engineer is a person who fixes things, like cars, houses, and other things.	3
2 Points	They build stuff.	2	An engineer solves problems by using math and science.	4
3 Points	I don't know.	0	I think engineers problem solve and think outside the box.	3
4 Points	Do not know.	0	There are many types of engineers, but an aerospace engineer uses simulations to decide what will happen and what could happen and then tries to make designs to improve what [is] not working to its full potential.	4

Gains in Conceptions of Engineering by Student Gender

When disaggregated by gender, significant gains in conceptions of engineering were reported for both female students ($t[770] = 9.21$, $p < .001$) and male students ($t[732] = 7.92$, $p < .001$) (Table 7). Note that after one year in the program, males had a higher mean conceptions of engineering ($\bar{x} = 2.34$), but females reported an overall higher mean gain (m difference of +.08).

Table 7.

Gains in Conceptions of engineering by Student Gender

	Prior to Program			After Program				
	n	*M*	*SD*	*n*	*M*	*SD*	Mean Gain	*t*
Females	771	1.73	1.12	771	2.20	1.15	.47	9.21**
Males	733	1.95	1.09	733	2.34	1.13	.39	7.92**

Note. * p < .05, ** p< .001

Differences between male and female levels of conceptions of engineering were significant prior to the program ($\bar{X} = 1.95, 1.73$, respectively), $t(1502) = 3.89$, $p < .05$, but not after the program ($\bar{X} = 2.34$, 2.20, respectively), $t(1502) = 2.31$, $p = .32$. There were no significant differences in gains between males and females, $t(1502) = 1.20$, $p = .23$. While females tended to make slightly greater gains than males in conceptions of engineering (m =.47, .39, respectively), students' growth was comparable, regardless of gender. Perhaps the slight difference in growth (m = .08) was enough to begin to close the gap that existed between the levels of the two genders before their involvement in the program.

Effect of Student-Fellow Engagement and Satisfaction

The post-survey contained five items that asked students to rate their engagement and satisfaction with their Fellow. Students rated their level of agreement (on a scale of 1-5) with the following: (1) I like talking to our Fellow, (2) Our Fellow makes learning more interesting, (3) I like having a Fellow in our classroom, (4) I am more interested in studying science because we had a Fellow in our classroom, and (5) Our Fellow helps me understand what we're learning in class.

ISSN:2149-8504 (online)

The items were coded as a response or non-response according to the level each student selected on the five-point, Likert-type items. For example, all students who circled a two, or Disagree, for an item were coded as a response on that variable; any other selection was coded as a non-response. This created five variables for each item, corresponding to the students' selections. An independent samples t-test was run at each level to analyze the significance of growth in conceptions of engineering according to how students responded.

The higher level of agreement students selected on the engagement and satisfaction items, the more they correspondingly gained in their conceptions of engineering. Table 8 lists the gains in conceptions of engineering from the beginning to end of the program according to how students responded to the five-point, Likert-type items. These data show that students who were more engaged and satisfied with their GK-12 Fellow (indicated by a neutral response, agreed, or strongly agreed) had significant growth in their conceptions of engineering; those who were not engaged and satisfied with their Fellows (strongly disagreed or disagreed with the items) generally did not.

Table 8.
Mean Gains in Conceptions of Engineering by Fellow Engagement / Satisfaction

Item	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I like talking to our Fellow	.20	.23	.41**	.43**	.53**
Our Fellow makes learning more interesting	-.02	.08	.33**	.50**	.51**
I like having a Fellow in our classroom	.07	.10	.26*	.44**	.55**
I am more interested in studying science because we had a Fellow in our classroom	.21	.26*	.40**	.49**	.61**
Our Fellow helps me understand what we're learning in class	.11	.46**	.26*	.45**	.52**

Note. * p < .05, ** p< .001

Students Involved for Two Years

Some students were involved in GK-12 for a second year, either as 8th or 9th graders (n = 220). They completed pre- and post-surveys for both years, so their conception of engineering was analyzed to determine significance of means across both years of participation. The first year mean growth of the subset of students with a second year (n = 220, m gain = .37) and the remaining students with only one year (n = 1302, m gain = .44) was not significantly different t(1520) = .749, p = .454. A repeated measures ANOVA was conducted to determine if means differed significantly during three time periods - prior to the program, after the first year, and after the second year. There were no significant outliers in the data, and the dependent variables were normally distributed when tested with the Shapiro-Wilk test of normality (pre = .079, post = .164). Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $\chi 2(5) = 5.18$, p = .976. No significant gains occurred between the end of the first year and the beginning of the second year (M = 2.10, SD = 1.16, p = .25), so the second year pre-survey results were not included in this analysis.

The repeated measures ANOVA revealed means differed significantly between the three tested points (F[2, 438] = 35.32, p < 0.001) (Table 9). Post hoc tests using the Bonferroni correction showed that the mean differences of students' conceptions of engineering prior to the program to the end of the first year (M = 1.91, SD = 1.19; M = 2.27, SD = 1.18, respectively) were significantly different (p < .001). Additionally, means after their second year of GK-12 involvement increased to 2.68 (SD = 1.17), which was significantly greater than their conceptions of engineering both prior to the program (p < .001) and after the first year (p < .001). There was a

ISSN:2149-8504 (online)

statistically significant increase in students' conceptions of engineering after one year of GK-12 involvement, and an even greater and statistically significant increase after the second year of involvement.

Table 9.
Gains in Conceptions of Engineering, Two Years of Involvement

	Prior to Program			After Year 1			After Year 2							
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	Diff. pre-post$_1$	Diff. pre-post$_2$	*F*	*df*	*p*
Total	220	1.91	1.19	220	2.27	1.18	220	2.68	1.17	.36	.77	35.32	438	<.001
Females	121	1.70	1.19	121	2.12	1.20	121	2.66	1.18	.42	.96	28.29	240	<.001
Males	98	2.13	1.34	98	2.46	1.14	98	2.68	1.16	.33	.55	8.85	194	<.001

Note: Diff. pre-post1 is the difference between means prior to the program and after the first year.
Diff. pre-post2 is the difference between means prior to the program and after the second year.

When analyzed by gender, the female mean scores differed significantly between their conceptions of engineering prior to the program, after the first year, and after the second year (F[2, 240] = 28.29, p < 0.001). Mean differences of female students' conceptions of engineering from these three points were statistically significant (p < .001). Male students' scores also differed significantly during the three time periods (F[2, 194] = 8.85, p < 0.001).

From prior involvement in the program (female $\bar{X}$ = 1.70, SD = 1.19; male $\bar{X}$ = 2.13, SD = 1.34) to the end of their second year of involvement (female $\bar{X}$ = 2.66, SD = 1.18; male $\bar{X}$ = 2.68, SD = 1.16), males had a mean growth of .55 in their conceptions of engineering, while females' mean growth was almost twice as much at .96. The scores prior to the program were significantly different, with the females' means lower than the males' ($\bar{X}$ = 1.70, 2.13, respectively), t(217) = 2.72, p = .007. By the end of two years of involvement, the growth females made in conceptions of engineering allowed them to catch up completely to males ($\bar{X}$ = 2.66, 2.68, respectively), t(217) = .14, p = .965 (see Figure 1).

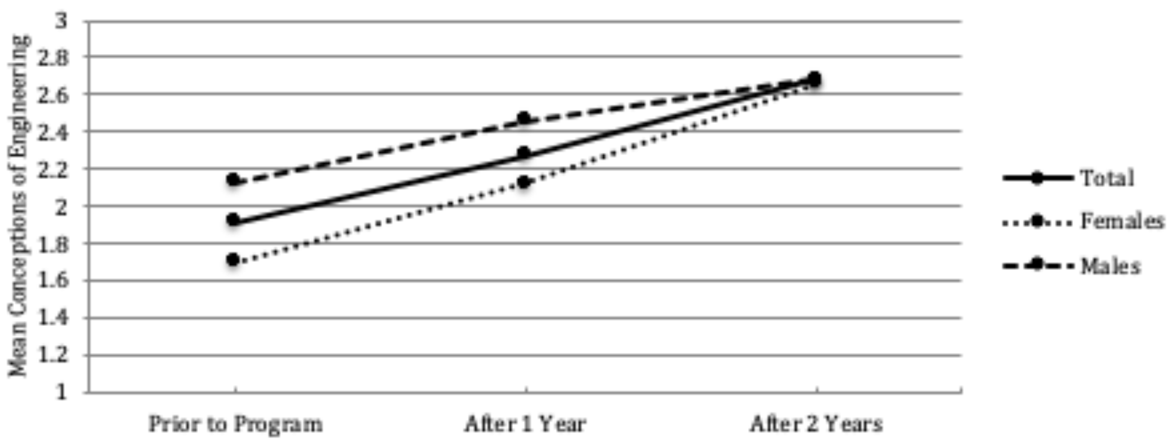

Figure 1. *Mean level of students involved a second year at three measured points*

Discussion

Overall, students who had a Fellow in their classrooms developed a significantly higher level of conceptions of engineering from beginning of the school year to the end, regardless of the gender of the student, or the gender or program of study of the Fellow. Like other middle school STEM career conception research (Knezek et al., 2013), this study found that in a single year, female students made slightly, but not significantly, greater gains than males (female M = .45, male M = .38). Although females grew marginally more than males in their conceptions of engineering, they typically started and ended at a lower level.

Still, a gap still existed in how males and females conceptualize the field. In the second year of involvement, though, females were making greater strides in their conceptions of engineering gains (M = .72). Overall, students who had a Fellow for a second year started and ended at a higher level than those involved for only one year, suggesting the second year may have played a greater role in students' development of understanding about the engineering field, and females may benefit even more from having a second year in these types of programs. This confirms prior research that indicates middle school engineering programs may have a greater impact on females' gains in conceptions of engineering (Christensen & Knezek, 2017).

Additionally, the more students were engaged and satisfied with their Fellows, the greater gains they made in their conceptions of engineering. It may be explained that students who ranked the "I like talking to our Fellow" item higher were more likely to have spent time conversing with their Fellows during class, asking their Fellows questions during class time, and staying after class to have conversations with their Fellows about science or their potential careers. This could partially explain why those who ranked this item higher made greater gains in their conceptions of engineering.

It can also be concluded that those students enjoyed having a Fellow in their classroom, enjoyed the presence of their particular Fellow, and felt it was motivating and academically beneficial to have one teaching them. Recent related research found that middle school students in authentic, project-based scientist partnership classrooms demonstrated significantly greater levels of positive attitudes, engagement, and confidence in science than their peers (Basche, Genareo, Leshem, Kissel, & Pauley, 2016). Teaching middle school students effectively requires much more than content and pedagogy; it is vital that teachers form relationships with students, make the students feel safe and secure, model caring and support, and tend to their personal and social development (Kellough & Kellough, 1999). Students in this study may have had more positive attitudes prior to, or because of, the GK-12 program itself, or had a Fellow who was a more effective communicator or teacher.

In similar research of African American students, Thompson and Lyons (2008) found that "six out of the ten experimental group students interviewed attributed some aspect of their engineering perceptions to previous involvement with a Fellow" (p. 201). In their study, however, all of the Fellows were engineering students. It should be noted that during four years of the GK-12 program, Fellows in engineering fields taught only eight out of the 34 classes, and yet students still made gains in conceptions of engineering across the board. This may be due to the symbiotic relationship and shared traits of engineering and science fields (Dugger, 1993), so having science Fellows still could have contributed to students' gains in conceptions of engineering.

One limitation of this study is that there is not enough information about the particular pedagogical contexts to explain differences. Whether or not an activity was presented from a standpoint of an engineer or a scientist may have affected how students understood engineering. It is also a limitation that the open-ended response was written, meaning literacy and writing skills could have affected the depth of student responses. Improved writing skills, or even increased motivation over the course of the school year, may have slightly affected the generally improved conceptions of engineering by the end of the year. Finally, there was no control group. Simply, putting the program into practice and working with real, research-consenting students made a control group infeasible. Consequently, it is difficult to claim that the GK-12 program was definitively responsible for students' gains in conceptions of engineering, although the effects of Fellow engagement and satisfaction on their conceptual growth were promising and supportive findings. Still, this study adds to the ever-growing

ISSN:2149-8504 (online)

body of research suggesting STEM partnership programs likely positively affect students' understanding of engineering and STEM fields (Lyons, 2011; Thompson & Lyons, 2008). Future research should examine these findings with a control group to isolate variables that may be affecting middle school conceptions of engineering.

Results of this study reinforce the call for science enrichment programs (McBride, Brewer, Bricker, & Machura, 2011). Since the GK-12 program has been phased out as an NSF initiative, schools and universities must continue to partner to provide authentic STEM experiences to schoolteachers and students. Not only are these experiences beneficial for graduate students (George & Tankersley, 2013) and teachers (Lyons, Thompson, & Addison, 2007), but they also appear to help students develop higher-level understanding of the engineering fields, particularly for students involved more than one year.

The Next Generation Science Standards were revised in part to ensure that concepts of engineering were being addressed in all schools, because "engineering wasn't in most states…a child could go through K-12 school without finding out what an engineer does" (Cardno, 2013, p. 26). Although a majority of predicted job growth in the United States is in STEM areas, there is still far more demand than supply in the job market, particularly among females in STEM fields (Dasgupta & Stout, 2014). Focused STEM intervention programs are of national importance because they can introduce K-12 students to careers in STEM and help grow the future job force (Shoffner & Dockery, 2015), and this study showed that the GK-12 program contributed to this by helping middle school students better understand engineering careers.

Conclusions and Implications

The purpose of this study was to investigate students' conceptions of engineering at the beginning and end of a year of a school-university STEM partnership program. Results suggested that this program may have been effective in helping students develop more sophisticated levels of understanding of engineering and alleviate some misconceptions about the engineering field. However, students' growth in conceptions of engineering was largely dependent on their level of engagement and satisfaction with their university Fellows. Some promising research in engineering-based, middle school summer camps supports our findings that effective, teacher and engineer partnership models can provide measurable effects on students' understanding of engineering (Hammack, Ivey, Utley, & High, 2015).

The next direction of research in this area should examine types of interactions that take place in the middle school classroom in an attempt to clarify how growth in conception of STEM fields is supported through student and Fellow relationship. Future researchers can also use and test the coding rubric developed in this study in conceptions of engineering surveys and further refine it, if needed, to establish a valid and reliable tool for examining students' responses. If confirmed to be effective, the process of using a single, open-ended item and scoring rubric could serve a different, and potentially more efficient, way to assess a large number of students' conceptions of engineering than the Draw-an-Engineer Test. Additionally, the researchers developed a system of categorizing engineering products and engineering gender from students' written responses to the item. This was not reported in the present study, but is available upon author request.

This research was unique because it looked not only at conceptual growth, but found some evidence that students' attitudes about the Fellows played a role in how much they learned about the engineering field. These, and other research results, offer encouraging evidence for the importance of similar programs in middle schools (Barrett, Moran, & Woods, 2014; Blanchard et al., 2015). To develop the future STEM workforce, schools must provide students the opportunities to learn about the careers and develop interest in them during the critical middle-level years or earlier, particularly if a goal to develop females' STEM career interest (Christensen & Knezek, 2017).

These findings also give some insight into the value of ensuring graduate students in middle school STEM intervention programs understand developmentally appropriate teaching strategies. Students at this age are more likely to be motivated to learn by teachers who care about their students, although this level of

ISSN:2149-8504 (online)

teacher warmth often declines during the middle school years (Hughes & Cao, 2018). Middle school students tend to respond better to teachers who are positive and constructive, and with whom they feel comfortable talking. Effective teachers tend not only to students' academic needs, but also to their social-emotional needs (Stronge, 2018). Those responsible for placing university Fellows in classrooms should choose and develop graduate students who not only have content and pedagogical knowledge, but also are personable and caring. Their interactions with students may play a larger role in developing middle school students' STEM career conceptions than previously known.

References

Banerjee, A. (2015). *Women's enrollment in engineering is growing. Databytes, Prism, American Society for Engineering Education*. Retrieved from http://www.asee-prism.org/databytes-sep/.

Barrett, B. S., Moran, A. L., & Woods, J. E. (2014). Meteorology meets engineering: an interdisciplinary STEM module for middle and early secondary school students. *International Journal of STEM Education*, *1*(1), 6.

Basche, A., Genareo, V., Leshem, A., Kissell, A., & Pauley, J. (2016). Engaging middle school students through locally-focused environmental science project-based learning. *Natural Sciences Education*, *45*(1). doi: 10.4195/nse2016.05.0012.

Blanchard, S., Judy, J., Muller, C., Crawford, R. H., Petrosino, A. J., White, C. K., Lin, F., & Wood, K. L. (2015). Beyond blackboards: Engaging underserved middle school students in engineering. *Journal of Pre-College Engineering Education Research*, *5*(1).

Cantrell, P., & Robinson, M. (2002). How do 4th through 12th grade science textbooks address applications in engineering and technology? *Bulletin of Science, Technology & Society*, *22*(1), 31-41.

Capobianco, B. M., Diefes-Dux, H. A., Mena, I., & Weller, J. (2011). What is an engineer? Implications of elementary school student conceptions for engineering education. *Journal of Engineering Education, 100*(2), 304-328.

Cardno, C. A. (2013). New K-12 science, engineering standards unveiled. *Civil Engineering – American Society of Civil Engineers*, *83*(6), 26-27.

Chambers, D. (1983). Stereotype images of the scientists: The Draw-a-Scientist Test. *Science Education*, *67*, 255-265.

Christensen, R., & Knezek, G. (2017). Relationship of middle school student STEM interest to career intent. *Journal of Education in Science, Environment and Health*, *3*(1), 1-13.

Cunningham, C. M., Lachapelle, C. P., & Lindgren-Streicher, A. (2005, June). Assessing elementary school students' conceptions of engineering and technology. Paper in the proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition.

Dasgupta, N., & Stout, J. G. (2014). Girls and women in science, technology, engineering, and mathematics STEMing the tide and broadening participation in STEM careers. P*olicy Insights from the Behavioral and Brain Sciences*, *1*(1), 21-29.

Davis, L. A., & Gibbons, R. D. (2002). *Raising public awareness of engineering*. Washington, DC: The National Academies Press.

DeGrazia, J. L., Sullivan, J. F., Carlson, L. E., & Carlson, D. W. (2001). AK-12/University partnership: Creating tomorrow's engineers. *Journal of Engineering Education*, *90*(4), 557-563.

Dugger, W. E. (1993). The relationship between technology, science, engineering, and mathematics. Paper in the proceedings of the Annual Conference of the American Vocational Association (Nashville, TN, December 3-7, 1993)

Eide, A. R., Jenison, R. D., Northup, L. L., & Mickelson, S. K. (2012). *Engineering fundamentals and problem solving (6th ed.)*. New York, NY: McGraw Hill.

Finson, K. D. (2002). Drawing a scientist: What we do and do not know after fifty years of drawings. *School Science and Mathematics*, *102*(7), 335-345.

Fralick, B., Kearn, J., Thompson, S., & Lyons, J. (2009). How middle schoolers draw engineers and scientists. *Journal of Science Education and Technology*, *18*(1), 60-73.

Genareo, V. R., Mitchell, J., Geisinger, B., & Kemis, M. (2016). University science partnerships: What happens to STEM interest and confidence in middle school and beyond? *K-12 STEM Education*, *2*(4), 117-127.

George, M., & Tankersley, R. (2013). Evidence of success of the GK-12 approach. In T. Spuck, K. Stoll, & S. Ortega, (Eds.), *The power of partnerships: A guide from the NSF Graduate STEM Fellows in K-12 in Education (GK-12) program* (pp. 119-128). American Association for the Advancement of Science.

Gilbert, G. E., & Prion, S. (2016). Making sense of methods and measurement: Lawshe's Content Validity Index. *Clinical Simulation in Nursing*, *12*(12), 530-531

Hammack, R., & High, K. (2014). Effects of an after school engineering mentoring program on middle school girls' perceptions of engineers. *Journal of Women and Minorities in Science and Engineering*, *20*(1), 11-20.

Hammack, R., Ivey, T. A., Utley, J., & High, K. A. (2015). Effect of an engineering camp on students' perceptions of engineering and technology. *Journal of Pre-College Engineering Education Research (J-PEER)*, *5*(2), 2.

Hirsch, L. S., Carpinelli, J. D., Kimmel, H., Rockland, R. & Bloom, J. (2007). The differential effects of pre-engineering curricula on middle school students' attitudes to and knowledge of engineering careers. Paper in the proceedings of the 37th ASEE/IEEE Frontiers in Education Conference, Milwaukee, WI.

Hughes, J. N., & Cao, Q. (2018). Trajectories of teacher-student warmth and conflict at the transition to middle school: Effects on academic engagement and achievement. *Journal of School Psychology*, *67*, 148-162.

Kelley, M. S., & Bryan, K. K. (2018). Gendered perceptions of typical engineers across specialties for engineering majors. *Gender and Education*, *30*(1), 22-44.

Kellough, R. D., & Kellough, N. G. (1999). *Middle school teaching: A guide to methods and resources*. Upper Saddle River, NJ: Merrill Publishing.

Knezek, G., Christensen, R., Tyler-Wood, T., & Periathiruvadi, S. (2013). Impact of environmental power monitoring activities on middle school student perceptions of STEM. *Science Education International*, *24*(1), 98-123.

Knight, M., & Cunningham, C. M. (2004) Draw an Engineer Test (DAET): Development of a tool to investigate students' ideas about engineers and engineering. Paper in the proceedings of The American Society of Engineering Education Annual Conference & Exposition, Salt Lake City, UT.

Komarraju, M., Swanson, J., & Nadler, D. (2014). Increased career self-efficacy predicts college students' motivation, and course and major satisfaction. *Journal of Career Assessment*, *22*(3), 420-432.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*, 159-174.

Leedy, P. (1997). *Practical research: Planning and design.* Upper Saddle River, NJ: Prentice-Hall, Inc.

Lent, R. W., Brown, S. D., & Hackett, G. (2002). Social cognitive career theory. *Career Choice and Development*, *4*, 255-311.

Lyons, J. S. (2011). AC 2011-161: GK-12 engineering fellows change student perceptions; Science fellows, not so much. Paper presented at the 2011 American Society for Engineering Education, 1-18. Retrieved from: https://www.asee.org/public/conferences/1/papers/161/view

Lyons, J., Thompson, S., and Addison, V. (2007). GK-12 engineering workshop for science and math teachers. Paper in the proceedings of the 2007 ASEE Annual Conference and Exposition, Honolulu, Hawaii.

McBride, B. B., Brewer, C. A., Bricker, M., & Machura, M. (2011). Training the next generation of renaissance scientists: The GK-12 ecologists, educators, and schools program at the University of Montana. *Bioscience*,

ISSN:2149-8504 (online)

61(6), 466-476.

McDuffie Jr., T. E. (2001). Scientists - Geeks and nerds. *Science and Children*, *38*(8), 16-19.

Mitchell, J., Levine, R., Gonzalez, R., Bitter, C., Webb, N., & White, P. (2003). Evaluation of the National Science Foundation Graduate Teaching Fellows in K-12 Education (GK-12) Program. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago, IL, April 21-25, 2003.

Mohr-Schroeder, M. J., Jackson, C., Miller, M., Walcott, B., Little, D. L., Speler, L., Schooler, W., & Schroeder, D. C. (2014). Developing middle school students' interests in STEM via summer learning experiences: See Blue STEM Camp. *School Science and Mathematics*, *114*(6), 291-301.

National Academy of Engineering. (2008). *Changing the conversation: Messages for improving public understanding of engineering*. Washington, DC: National Academies Press.

Oware, E., Capobianco, B., & Diefes-Dux, H. A. (2007). Young children's perceptions of engineers before and after a summer engineering outreach course. In Frontiers In Education Conference - Global Engineering: Knowledge Without Borders, Opportunities Without Passports. 37th Annual ASEE/IEEE, S2B-3 – S2B-8.

Page, C. A., Lewis, C. W., Autenrieth, R. L., & Butler-Purry, K. L. (2013). Enrichment experiences in engineering (E3) for teachers' summer research program: An examination of mixed-method evaluation findings on high school teacher implementation of engineering content in high school STEM classrooms. *Journal of STEM Education: Innovations & Research*, *14*(3), 27-33.

Rockland, R., Bloom, D. S., Carpinelli, J., Burr-Alexander, L., Hirsch, L. S., & Kimmel, H. (2010). Advancing the "E" in K-12 STEM education. *Journal of Technology Studies*, *36*(1), 53-64.

Shoffner, M. F., & Dockery, D. J. (2015). Promoting interest in and entry into science, technology, engineering, and mathematics careers. In P. J. Hartung, M. L. Savickas, & Walsh, B. W. (Eds.). APA handbook of career intervention, Volume 2: Applications. APA handbooks in psychology (pp. 125-137). Washington, DC: American Psychological Association.

Stronge, J. H. (2018). *Qualities of effective teachers*. Alexandria, VA: ASCD.

Tafoya, J., Nguyen, Q., Skokan, C., & Moskal, B. (2005). K-12 outreach in an engineering intensive university. Paper in the proceedings of the 4th ASEE/AaeE Global Colloquium on Engineering Education, Australasian Association of Engineering Education.

Thompson, S., & Lyons, J. (2008). Engineers in the classroom: Their influence on African-American students' perceptions of engineering. *School Science and Mathematics*, *108*(5), 197-211.

Tonso, K. L. (2006). Student engineers and engineer identity: Campus engineer identities as figured world. *Cultural Studies of Science Education*, *1*(2), 237–307.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, *4*(1), 45–69.

Vosniadou, S. (2007). Conceptual change and education. *Human Development*, *50*(1), 47-54.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction*, *11*(4), 381-419.

Yap C., Ebert C., & Lyons J. (2003) Assessing students' perception of the engineering profession. Paper presented at the South Carolina educators for the practical use of research annual conference, Columbia SC, February 28, 2003.

Yoder, B. L. (2014). *Engineering by the numbers 2013-2014. American Society for Engineering Education*, retrieved from: https://www.asee.org/papers-and-publications/publications/14_11-47.pdf

ISSN:2149-8504 (online)

Appendix A. Response coding rubric

Code	Rule	Examples
0	Student response had nothing to do with the question asked.	I don't know.
1	1) Response displays significant **misconceptions** about engineers 2) Or, response equates engineers to **mechanics** or **train workers/operators** (Knight & Cunningham, 2004)	1) Engineers work in hospitals taking care of the sick 2) Fixes car motors 2) Works on cars or trains
2	1) Response shows a vague understanding of engineering but uses very **abstract descriptions** that could apply to other disciplines besides just engineering 2) Or, response includes variations of **BUILDS, MAKES,** or **FIXES**. (Fralick et al., 2009) 3) Or, provides a concrete product example	1) Electricity 1) Uses science and math 2) Builds things 2) Builds cars and computers 2) Works on cars and electronics 2) Construction 3) Makes things like computers
3	1) Response describes one function of an engineer, such as **problem solving, researching, developing, designing, testing, operations, sales, consulting, teaching** (Eide et al., 2012) **managing,** or **evaluating** (Landis, 2007), **improve** 2) Provides more than one concrete example	1) Designs things 1) Inventing things 1) Creates or invents things 1) Problem-solvers 1) Tests cars, computers, etc. 1) They do lots of things like teaching 2) Makes things like computers, cars, bridges…
4	1) Response includes **multiple functions** of engineers, as described in "code 3" (Eide et al., 2012; Landis, 2007) 2) Or, response includes an example of engineering and states that **they help improve society or their organization** (Eide et al., 2012; Landis, 2007) 3) Or, response includes **codes 2 and 3** together (Landis, 2007)	1) Engineers research and design computers, buildings 1) Designs, makes and fixes electronic and mechanical equipment 1) Work in different areas like testing, production, and maintenance 2) Engineers design things in medical fields that help people and doctors 2) Help society by inventing things people need and use. 2) Help companies they work for make $ by designing things they need 3) Use problem solving to build cars, computers, etc. 3) Use science and math to design medical instruments, bridges…

ISSN:2149-8504 (online)

Journal of Research in STEM Education

Vol 4, No 2, December 2018, 146-158

RESEARCH REPORT

Inquiry Beliefs and Practices in an Urban Low SES Elementary Classroom: A Case Study

Boby Jeanpierre

University of Central Florida, USA

Abstract: *This case study explored the inquiry beliefs and practices of an elementary teacher in an urban low SES school. The case study included an array of data collection methods: teacher interview, classroom observations of teacher's practices (3-5) days a week over six months, weekly journal reflections, teacher's responses to an inquiry survey, responses to the Excellent Science Teaching Educational Evaluation Model survey and the school-level principal was interview about her perceptions of the teacher's science instructional practices. Findings indicated that the teacher's beliefs and practices did align and that she did consistently use structured and guided inquiry practices, but rarely used "full inquiry" as described in the National Science Education Standards. Key to this teacher's use of inquiry was the professional education she had received that both modeled and provided opportunity for her to use various inquiry practices. She also had a belief that all of her students deserved to have quality science experiences and that she could provide it best through inquiry. She sought to increase students' interest in and experiences with doing science. Time was sometimes a hindrance to the completion of inquiry activities and inquiry-based curricula materials were also important to facilitating the teacher's use of inquiry.*

Keywords: Science, urban, elementary

Introduction

The new Framework for K-12 Science Education (NRC, 2011) has integrated inquiry and describes eight practices in science and engineering. Five of the eight practices are integral to inquiry. They include: asking questions, planning and carrying out investigations, analyzing and interpreting data, conducting experiments and obtaining, evaluating and communicating information. It is important to understand that the practices do not abandon inquiry but seek to inform science teaching and learning based on insights gain from recent science education research and lessons learned from standards implementation.

The need to examine teachers' day-to-day science inquiry practices and their beliefs remain relevant to the improvement of K-12 science teaching and learning. There is still a lot we do not know about quality inquiry instruction. In fact, there is a gap in what is known about why teachers decide to use inquiry and how they enact it in their classrooms. Researchers support the need to learn more about the inquiry perspectives of pre-service and in-service teachers in the field (Pennuel & Fishman, 2012; Keys & Bryan, 2001). Additionally, we know even less about why teachers in low SES urban science classrooms choose to use inquiry. Therefore, it is apparent that more research, which describes teachers' classroom practices and reasons for doing inquiry in low SES urban settings is needed. This research aimed to address this gap in the literature using a case study

[1] Corresponding author. School of Teaching, Learning and Leadership & Department of Educational Human Sciences, College of Education, University of Central Florida, PO Box 161250 Orlando, FL 32816, E-mail: bobby.jeanpierre@ucf.edu

Jeanpierre, B. (2018). Inquiry Beliefs and Practices in an Urban Low SES Elementary Classroom:A Case Study. *Journal of Research in STEM Education*, *4*(2), 146-158.

ISSN:2149-8504 (online)

investigation of an elementary teacher's beliefs about inquiry and how she implemented it in an urban low SES classroom.

This manuscript presents rich descriptive case study findings obtained from the first teacher selected to participate in this longitudinal study. Documented below are descriptions of the first case study teacher, Martha, her inquiry beliefs, practices and lessons learned as she carried out inquiry science lessons with her fifth grade students. Next is the literature review and conceptual framework for the study.

Literature Review and Conceptual Framework

Inquiry has a long history in science and science education literature. For example, Dewey (1910) advocated that children experience science and not be passive recipients of ready-made knowledge. He contended that knowledge is "not information, but a mode of intelligent practice and a habitual disposition of mind" (p.124). Schawb (1962), in "The Teaching of Science as Enquiry" echoed Dewey's sentiments on the importance of inquiry-based teaching and learning. He stated:

> In the very near future a substantial segment of our public will become cognizant of science as a product of fluid enquiry, understand that it is a mode of investigation, which rests on conceptual innovation, proceeds through uncertainty and failure, and eventuates in knowledge which is contingent, dubitable, and hard to come by (p. 5).

Inquiry has been heralded as essential to student development of what Dewey (1910) called habits of mind- way of thinking that promotes scientific reasoning skills. The inclusion of inquiry is a constant in science education. The K-12 Framework for Science Education: Practices, Crosscutting Concepts and Core Ideas (NRC, 2011) supports inquiry. The National Science Education Standards emphasized the need for teachers to implement more "inquiry-based" science teaching and learning opportunities. In fact, in the NSES (1996), inquiry is viewed as the key strategy to effective science teaching. "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (p. 31). The National Science Education Standards support that when children inquire into the natural world they: 1) ask questions, 2) plan investigations and collect relevant data, 3) organize and analyze collected data, 4) think critically and logically about relationships between evidence and explanations, 5) use observational evidence and current scientific knowledge to construct and evaluate alternative explanations, and 6) communicate investigations and explanations to others." This is only one of a myriad of definitions of inquiry and other well-noted sources exist. For this study, the National Science Education Standards (1996) definition of inquiry was used to help frame the context of how inquiry teaching was represented in the case study classrooms.

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (p. 23).

In contrast to this perspective on inquiry is that in many instances workbooks and textbooks dictate what science instruction occurs in the classroom. Huber and Moore (2001) argued that unfortunately, hands-on activities recommended by science textbooks and worksheets are typically presented as step-by-step instructions. If a step-by-step approach is followed, it may not foster inquiry practices. Teachers' use of inquiry methods maybe linked to their beliefs and practices.

Researchers have provided a strong literature foundation for the importance of teachers' beliefs (Lotter, Dickenson, Blue, & Rea, 2018; Kaymakamoglu,, 2018; Nespar, 1987; Richardson, 1996; Pajares, 1992; Parke & Coble, 1997; Bryan & Abell, 1999; Abell & Smith, 1992; Haggerty, 1992; Hewson & Hewson, 1989; Jasalavich, 1992; & Lorsbach, 1992), which revealed that they are central to their classroom practices. The importance of a teacher's beliefs is situated within the context in which teaching and learning occurs. Teachers' beliefs as related to the abilities of urban learners are also important for they may affect what they do in the classroom.

ISSN:2149-8504 (online)

How teachers perceive their role as science teachers may have profound effects on what they do (O'Laughin, 1991). And other researchers suggest that, "Beliefs are not easily changed. Brand and Glason (2004) argue that the more important a belief is, the more resistant it is to change.

Urban classrooms can hold distinct challenges for teachers desiring to teach using learner-centered practices (Leonard, Barnes-Johnson, Dantley, and Kimber, 2011). It is a welcome occurrence when urban elementary teachers, embrace science reform instructional practices, like inquiry. Additionally, urban science classrooms are particularly complex cultural interface zones in that the cultures interacting are not only those of the students and teachers but also that of science as an intellectual discipline" (Norman, Ault, Bentz & Meskimen, 2001, p. 1103). Elementary science instruction matters even more in large urban settings given the huge number of obstacles these students face. In fact, Lawrenz, (1986) argued that if "elementary students aren't exposed to quality science education in their beginning years; they may be at a significant disadvantage" (p. 654). Rist (2017) goes even further and argues that "The ability of the schools to generate social and economic opportunity for this massive group of children when the rest of the social structure works to block their way onto the mobility escalator is simply quite limited" (p.15). Rist's observation about America's urban schools only increases the need for high quality teaching in these schools.

With the importance that the National Science Education Standards place on students experiencing inquiry learning in schools, and the fact that we need to learn more about teachers' views about the goals and purposes of inquiry, and the processes by which they carry out inquiry (Keys & Bryan, 2001) increases the importance of how inquiry is enacted in low SES urban school settings. The lenses provided for organizing and categorizing findings of the study were presented in the literature and conceptual framework and situated in the importance of teacher's inquiry beliefs and practices.

Research Questions

1. What were Martha's beliefs about inquiry?
2. How did Martha facilitate inquiry?

Methods

A case study method was used to conduct this research. A case study, as defined by Yin (1989; 2015), is an empirical inquiry into real-life context in which multiple sources of evidence are used. The school selected for this study was an urban low SES elementary prek-5 school with 50% or more of students on the free-and reduced lunch program. Martha taught at this low SES school and reported on her inquiry beliefs survey that she taught science regularly, which met the main criteria for the study. She accepted the invitation to participate in the study.

The case study school, Loyola Elementary School was located in a large southeast urban school district and had 746 K-5 ethnically diverse students. Of those students 415 (55.6%) were Hispanic, 190 (24.5%) were Caucasian, 86 (11.5%) were African American, 25 (3%) were Asian and 30 (4%) were classified as other. Of the 746 students, 533 (72.9%) received free and reduced lunch. One-hundred and twenty-four (16.6%) of the students received Education for Students with Exceptionalities services and 211 (28.3%) received English Speaking Students of Other Languages services.

Over six months, multiple sources of qualitative data were collected. The data sources included: three to four days weekly classroom observation field notes that were video and audio taped, an inquiry beliefs and practices survey; a survey on constructivist beliefs "Excellent Science Teaching Educational Evaluation Model" developed by Burry-Stock (1991), teacher interview, teacher journal notes, and a principal's interview. This case study elucidated important findings about Martha's beliefs and her actual day-to-day inquiry practices in an urban low SES elementary science classroom.

ISSN:2149-8504 (online)

Data Analysis

The case study resulted in the compilation of rich, thick field notes that described the teacher's inquiry beliefs and practices. The data were triangulated across the fore stated multiple sources of data and then analyzed for recurrent themes and patterns, which were reported in this manuscript. From the diverse methods described, a rich thick descriptive case study of Martha's beliefs and practices was constructed. Pseudonyms were used throughout the manuscript for participants in the study and the elementary school.

The Case Study

Martha's Class Demographics

The fifth grade students in this study were part of a self-contained classroom of 21 students. Of these 21 students, 9(42.8%) were boys and 12 (57.1%) were girls. Nine (42%) Hispanic, 8 (38%) Caucasian, 3(14.2%) African American and 1(4.7%) were Asian. Approximately, twenty-three per cent of students received free and reduced lunch and 43% were classified as ESE and 9.5% were ESOL.

Martha –Who she is and why she Uses Inquiry Science

Martha, a Caucasian female taught fifth grade at Loyola Elementary School. She was in her sixth year of teaching and has certification in elementary education and ESOL. She provided the following details of her professional teaching preparation and why she uses inquiry.

My undergraduate work was split between two colleges. I began in south Florida at a private college, and then transferred to a public college in Massachusetts where I earned a BS in Elementary Education. During undergraduate work, I took one science methods class. I successfully completed both the Massachusetts and Florida teacher certification exams to become an elementary teacher.

Teaching science as inquiry was a gradual process born out of necessity. In my fourth year of teaching I moved to Massachusetts where I took a position as a fifth grade teacher in a middle school. After accepting the position, I learned I would be responsible for teaching science to the fifth graders. Wanting to be successful I had to begin to revamp my teaching. Until this point, science teaching consisted of assigning reading from the text and asking questions as dictated in the teacher's manual. I had neither significant science knowledge nor any desire to enhance my understanding. I was scared of teaching science because I did not believe I understood the topics well enough to answer any questions the students may have posed. I did not want to seem uneducated by my students, their families, or my colleagues but I really did not know what to do.

I started in small ways. I read the science text and I tried the activities outlined in it. Little by little my confidence grew, as did my understanding of the science concepts. After a year, I moved to a new state and took a position teaching k-5 science. At this point I knew textbook reading was not providing a quality experience for the students, but I was not familiar with science as inquiry. I began the year doing what I knew, activities from the text. Almost simultaneously two significant events introduced me to science as inquiry. I attended a week long professional development workshop where I was introduced to 5E inquiry. The workshop was significant because in additional to being introduced to a successful teaching methods, I was given the opportunity to participate in the inquiry process with other teachers and I was provided lessons that used inquiry based instruction. The workshop allotted time to implement and discuss inquiry-based instruction which inspired me to try them in my own classroom. Having lessons that were approved by the county and based on inquiry instruction, I had the tools immediately available so I was able to begin to change my teaching practices, while the inspiration was fresh.

At the same time I began working on a Master's degree at the local university. Within this program, there was an emphasis on science and mathematics education. Considering my most recent work experiences, I chose to focus on the science education. Within this program I was exposed to research and best practices that solidified my beliefs in the necessity of teaching science as inquiry. A key element of the program was expertise of the professors. One particular professor was passionate about science as inquiry and her dedication

ISSN:2149-8504 (online)

empowered me to model myself after her. During her class, the professor guided the class on standards based lessons using inquiry instruction. After modeling the process, she regularly would challenge the class to think more deeply about a particular point and after class expect us to reflect on the experiences. Seeing the professor walk to class lugging boxes of supplies so we had the opportunity to experience inquiry instruction, both as a student and teacher was a meaningful experience for me. In additional to the theory and experiences of using inquiry instruction she regularly addressed the practical issues of inquiry instruction such as time managements, buying and organizing of consumable supplies, administration support, or lack thereof, and communicating with colleagues about successful, and unsuccessful inquiry experiences. This professor provided the inspiration, guidance, and support that led me to commit to using inquiry instruction as a powerful tool in my classroom.

I taught elementary school, in various positions, for five years before beginning a master's program. During those years, I taught fourth and fifth grades in an affluent suburb of Fort Lauderdale, fifth grade in an affluent community in western Massachusetts, and K-5 science and fifth grade in an urban Orlando school. In Orlando, I taught at a low SES urban elementary school which had a large number of Latino students. This school had many of the often reported problems in some large urban school districts, substantial student mobility, limited parent support and involvement and students performing at low academic levels.

Using inquiry to teach science is driven by my personal belief that students in my classroom deserve the "best education "I can provide and I believe that inquiry instruction is a huge part of that "best education." Teaching is not about doing what is easiest or most comfortable for me, it is about inspiring my students to ask questions and seek answers to those questions while learning to believe in themselves. I want to inspire my students to find challenges exciting and look for opportunities to expand their understanding of their world. Science as inquiry, to me, is the best way for me to ignite a love of learning in my students.

My administration did not cheer my efforts, nor did they criticize them. I teach science as inquiry because it is the right thing to do. My administrators have faith that I will cover the mandated curriculum and if I choose to enhance my students' experiences in science, while still covering all the requirements, they trust my judgment. With science now being tested on state standardized tests, science classes are getting more attention from administration. However, they are not familiar enough with inquiry instruction or their own science understanding to demand inquiry instruction from all staff.

My success in teaching science as inquiry is completely student centered. Teaching science as inquiry is hard work and there are days when time and tempers are short. I have days when I simply feel too overwhelmed with student behavior, administrative requests, and life in general to teach using inquiry instruction and the easy way out is to assign text reading. Then, I think that the successes are my inspiration to keep going. There is the little girl that said, "I never liked science before this year, but now it's fun." There are the days when students notice science is not on the agenda and ask, "Why not?" There are the notes from parents thanking me for getting their child excited about school. A personal favorite was after a mealworm inquiry a parent sent a note describing her son's excitement over the inquiry. She said, "He was like a kid at Disneyland." Success like that is all the inspiration I need to keep using and improving my inquiry instruction.

Martha's Beliefs

Martha stated her science instruction beliefs during an interview, which centered on inspiring students to become life-long learners who asked their own questions and sought out information. She stated:

> I believe teachers have an opportunity and an obligation to inspire and empower their students, especially in elementary science class. Ideally, I want students to feel personally changed by their experience in my classroom. Teaching is not about spouting information into students' heads that are waiting to be filled; rather it is the inspiration that creates life-long learners filled with curiosity. As students study science in my classroom, I want them to be inspired to ask questions, seek answers and share those ideas with others to complete the learning cycle.

ISSN:2149-8504 (online)

When describing her beliefs about the role of the teacher in the science classroom, Martha saw herself as a facilitator of student learning and linked students' success in science to the learning environment provided.

> Teachers are the facilitators that maximize each student's ability to reach his/her personal best. Success in the science classroom is best reached through a learning centered environment that encourages sharing thoughts and idea in avenues such as small group discussion, guided inquiry experiments, full inquiry experiences and textbook support.

Martha rated herself as five (on a scale of 1 almost never to 5 almost always) when she responded to survey item one Part 2: "I am a facilitator of students learning."

Martha had strong convictions about the importance of providing students opportunity to participate in inquiry. She believed that the positive attitudes toward the study of science should be instilled in students early during their elementary school years:

> It is my responsibility to ensure my students have the necessary experiences early and frequent exposure to an involvement with science that will help create a love of science and learning that will follow them throughout their lives.

Martha's response to why she chose to teach science using inquiry elucidated additional details about her beliefs about her role as the teacher in supporting student learning, guiding and providing explanations and explorations to students as they investigated science concepts, regardless of their academic ability. Martha stated:

> Using inquiry allows students to become involved in science lessons in a way that engages all students, regardless of academic ability. Students' curiosity is sparked as they are presented scientific concepts to explore using hands-on involvement. Using inquiry affords students the opportunity to explore concepts and find, then share, their discoveries with classmates, which ultimately helps the student solidify their scientific learning. As their teacher, it is essential I support their learning by providing support, guidance, and explanations during explorations and discovery .

Martha was not typical as it related to elementary science teaching at her school. Many teachers at the school simply avoided teaching science and the principal did not emphasize science as a core subject that teachers needed to teach.

During an interview, the principal of the school was asked about her commitment as the leader of the school to science instruction and she stated, "When it is tested we will teach it." This comment followed the principal's detailed explanation about the time she wanted teachers to commit to reading and mathematics instruction at her school. Hence, Martha's commitment to science instruction was even more remarkable, since the principal's perspective was focused on teaching what is tested. Martha still managed to meet the principal's expectations for reading and mathematics instruction.

Martha's Instructional Practices

In addition to understanding Martha's beliefs about inquiry science instruction, this research aimed to elucidate what were her instructional practices and reasons for choosing to use inquiry in an urban low SES elementary classroom. An examination across data sources revealed that Martha was consistent in stating the importance of science teaching and her role in fostering a "love of learning in her students" as to why she chose to use inquiry practices. In an interview, Martha stated:

> Exposing children to scientific process skills from an early age is essential in creating positive feelings toward the study of science. If children are frequently engaged in science lessons which probe for deeper understanding of science concepts the foundations for life-long learning is set. Actively participating in science lessons is a critical aspect for building the basis for future learning.

ISSN:2149-8504 (online)

Martha chose to use inquiry along with other methods during science instruction because she believed that "elementary students were being exposed to science for the first time and it was the teacher's role to inspire the desire to constantly seek more knowledge." In addition, she expressed her personal feelings about affecting student learning: "I am passionate about finding the most effective ways of stimulating and sustaining the love of learning in my students."

As an elementary science teacher, Martha's instructional practices also included other approaches and resources. The textbook was viewed as a resource and not the center of science instruction. These conclusions were further supported in the teacher's responses to inquiry survey item 7: "I do not depend on the textbook." Martha self-rating was that she seldom used the textbook. Furthermore, classroom observations supported Martha's statement about not being dependent on the textbook during science instruction. She did use a number of hands-on and/or inquiry based activity sheets during science instruction.

This research revealed that Martha's inquiry practices were facilitated by the use of a variety of curricula materials: 1) school district provided science curricula (district developed science lessons) which often followed the 5-E model (engage, explore, explain, extend/apply, evaluation, or less often full and guided inquiry, and 2) teacher selected worksheets which included several different science process skills in the lesson format and/or were mostly structured inquiry lessons.

Martha consistently taught science a minimum of three times a week from 45 to 60 minutes per lesson. The amount of time Martha committed to science instruction was in itself commendable and not the norm at her school.

Martha- An Inquiry Lesson

The following example documents Martha's inquiry practices were further documented when teaching lessons in the unit, "Living Things and Their Environment." The inquiry lesson described below was titled: "Can Seeds Germinate Without Soil?" This seven-day inquiry lesson provided students the opportunity to investigate factors that affected plant growth beginning from seeds. In her reflection, Martha stated the focus of the lesson was, to give students the freedom for the first time to generate and carry out their own testable questions. The following exchange occurred during an observation:

> Zane: No, I don't suppose that an organic organism may germinate without soil. First, because the soil helps fertilize the plant. Second, because it gives the roots an area to hold onto. Finally, it will give the roots water and nutrients they need.
>
> Malos: The seeds can't germinate because soil has the nutrients.
>
> Martha: Thank you for your wonderful thinking. Now, is this a testable or researchable question?
>
> Class: Testable.
>
> Martha: Terrific!

During this exchange, Martha did not see the need to probe students' thinking deeply, nor did she address their concepts of seed germination. She decided to focus on whether or not students could test their ideas. Next, Martha had students participate in a follow-up activity called, "All Write." In this activity everyone gets to participate by writing their ideas down on paper. First, students were instructed to think about how they could design an experiment to test the ideas that seeds need soil. Then they were to use pictures and words to explain how the experiment should be designed. Martha asked students if they had any questions, to which they responded, "no." Then Martha instructed students to begin.

Once students had completed their designs, Martha asked for whole class sharing of ideas. Students had been supplied baggies to use as containers for their seeds. Most of the student's responses centered on putting the seed in one baggie with dirt and in different baggies put the seed with nothing but water. Martha commended students on their ideas. Then she also suggested that students use pseudo soil (wet paper towels)

ISSN:2149-8504 (online)

as a third baggie experiment. Students were then given 10 minutes to build their experiments. It actually took the students 15 minutes but in all they did finish their designs. After baggies were prepared and sealed students drew on their data collection sheets observations for day one. For the next seven school days students observed, and documented what occurred with their seeds.

Overall, Martha was pleased with this inquiry for she believed that it facilitated students' learning and formulating conclusions. Students were shocked to see that the most conducive environment for the seeds to sprout was the pseudo soil. Not only did the seeds germinate, in two cases, the seedlings actually popped out the baggie. Hence, their results contradicted their predictions.

The two students whose seeds had the most growth were particularly proud of themselves and were very excited to share their thoughts on why their seedlings grew so well. The two students actually had the idea to transplant their seedlings into a paper cup with dirt to see if they would continue to grow. The transplanted seeds were left over a long weekend. Upon their return, the seedlings had grown so tall that they flopped over the side of the cup. The student scientists could not let their little plants die, so they took pencils, without help or suggestion from the teacher, and used string to tie their plants to the pencils for support. At this point, Martha believed the plants might grow to full size, so she sent the plants home with the two students.

During this inquiry, Martha and her students also learned a few procedural details too. They put the seeds into a baggie of water, which was fine, as long as the baggie remains sealed. The students enjoyed watching the seed coat peel off the plant and were a bit sad to see the seeds die, but one real lesson learned by all, teacher included, was rotten seeds stored in baggies of water have a terrible odor! Once the baggies were opened to more closely examine the seeds, the stench quickly filled the classroom and the students were not shy about bemoaning the fact that their noses were assaulted by the smell.

Martha stated that the inquiry was memorable. She believed it was a great experience for students to see that the smelly seeds caught her off guard and for the students to be able to experience doing science first hand. As they did this inquiry, they learned that things may develop differently than anticipated, but continue to observe, record, and draw conclusions from the experience was the best part of learning.

Because this inquiry occurred in the spring of the school year, students were very familiar with being able to plan their own investigations. Martha commented about the design of the inquiry:

Having two baggies to compare was adequate, but the next time I lead this inquiry, I will add one more baggie containing a different mixture. By adding a third mixture to the inquiry I can advance students' thinking by having them classify similarities and differences of the baggies as they observe which are suitable for plant growing and which are not. Having a third baggie may also help students distinguish the importance of variables in the inquiry, because up to this point in their school year, identifying variables was still tricky for some students .

Discussion and Conclusions

An examination of the case study data elucidated findings concerning Martha's beliefs and use of inquiry practices. Martha's beliefs and practices did align and her professional preparation influenced her use of inquiry substantially. The alignment of beliefs and practices has been reported to be beneficial when facilitating inquiry instruction (Author, 2006). Martha identified two events that help shaped her use of inquiry: 1) district provided workshops on using 5-E model and 2) university Master's program in science and mathematics where the professor showed and eagerness for teaching science as inquiry and modeled its use. Martha saw herself as a facilitator of student learning and believed that it was her responsibility to affect positive attitudes in all of her urban low SES students toward science during their elementary school years, regardless of ability. Martha also reflected on her practice and looked for opportunities to improve her use of inquiry.

Like a number of elementary teachers, Martha did not believe that she could teach science well and lacked the confidence to do so. She sought out needed professional development and extended learning experiences through a Master's program where she could continue to develop her understanding of inquiry while learning additional science and mathematics content. She believed that this was extremely beneficial to her continued use of inquiry in the classroom. Martha explicitly stated that the instructor's modeling of inquiry and apparent excitement about teaching science using inquiry made a positive impact on her teaching practices. Martha's experiences show that university level science educators have power to help shape and mold how our students think about their own teaching.

As we examine reform teaching practices, such as inquiry, it is important that teachers have continuous ongoing professional development to support them. Opfer and Pedder (2011), argue that conceptualizing teacher professional learning as key and is advanced as a complex interactive interaction of the teacher, the school and the learning activity. I would add that university teacher education programs are also major players in sustaining the quality and nature of science teachers' professional development. Martha was extremely positive about the inquiry learning experiences saying that they really helped her to venture out and do inquiry with her students. As a science education community, we need to make sure that we not only model "best practices in science instruction" but also partner with local school district curriculum personnel to assist them in providing professional development opportunities focused on science reform instructional practices, like inquiry, as a means to support teachers' use of inquiry with their students.

In response as to why she chose to teach science using inquiry Martha believed that inquiry allowed students to become involved in the lessons and it was essential that she facilitate their learning by providing support, guidance, and explanations during explorations and discoveries. Martha's perspective on teaching inquiry aligns with other teachers. Kazempour and Amirshokoohi, (2014) found that their "participants discussed the importance of motivating students by engaging them in inquiry-based, student-centered, contextualized and relevant learning opportunities" (p. 302). This is important because Martha taught in an urban low SES elementary school and these schools are often depicted as having an array of problems, including poor pedagogy (Haberman, 1990; Rist, 2017) Also, teachers in these low SES schools have their own set of distinct challenges. It has been reported that teachers within these larger urban schools in lower SES communities tend to develop a lesser "sense of community" among each other than do other schools (Brik and Driscoll, 1988). Therefore, it is encouraging that Martha not only sought to improve her inquiry teaching practices but was committed to providing inquiry learning experiences to her students. Martha did not always guide students to deeper understanding of the science content under study, nor did she always provide students with direct answers to their questions. Rather, she often attempted to use guiding and follow-up questions when facilitating inquiry experiences. She sought to increase students' interest in and experiences with doing science. Martha's beliefs about teaching science as inquiry to all of her students was supported by her classroom instructional practices.

Martha provided her students with a number of opportunities to participate in structure and guided inquiry and hands-on activities. She did not depend on the textbook as a resource, but she did use a number of commercially produced inquiry activities and school district- developed inquiry-based activity packets.

Rist (2017) asks very specific question about teachers in urban schools- their quality, their longevity, and their intentions towards the poor. The question is very straight forward, "Who wants to teach in urban schools and why?" (p.20). Martha was aware of the challenges she faced in her urban elementary school; yet , Martha's actions demonstrated that she enjoyed teaching inquiry-based science to her students. Urban schools often have what may seem as insurmountable problems, but Martha was positive about her experiences. Martha believed that she could make a difference. She sought out additional professional development and started a master's degree program that focused on improving elementary teachers' science and mathematics content knowledge.

Stevens (1993) argues that "current teaching practices in many urban school classrooms have been responsible for keeping the academic achievement of poor and minority students at a very low level" (p. 273). These teachers' practices that do not uphold high academic standards for their urban minority students, may, in part be due to their own feeling of lack of preparedness to teach elementary science. In a 2013 survey, Horizon Research, Inc. found that only 39 percent of elementary teachers feel very well prepared to teach science (p.7). In Martha's case, she countered this trend. She took advantage of professional development opportunities and started a master's program to improve herself. Also, she sought to provide her students with a wide array of science experiences through reform science instructional methods. Martha's practices and espoused beliefs support that she enjoyed teaching inquiry to her students and was committed to providing them with learning experiences to increase their interest in science. Central to Martha's inquiry instruction was to focus on students' learning needs. She reflected after the conclusion of one inquiry experience:

> The lesson learned for me is I must work on keeping my goals focused around student learning. Rescheduling an inquiry is far better than rushing to finish one and cross it off the lesson plan. If one takes the time to plan and inquire then it is a disservice to the students to not implement it correctly.

Martha was student centered. Alkove and McCarty (1992) argued that "constructivist teachers believe learning in school should be student-centered as opposed to teacher-centered" (p. 20). Other researchers (Furtak, Seidel, Iverson, & Brigs, 2012) concur with Alkove and McCarty (1992) that the teacher is very important and should actively guide student activities in the context of inquiry learning. The previous descriptions of Martha's inquiry practices show that gets it. She played a crucial role in facilitating students' learning through inquiry.

For Martha, time was sometimes a hindrance to the implementation of an effective inquiry and she often had to focus on the end product of the activities and not processes. Both time and focus on learning goals have been identified as hindrances to effective inquiry. Horizon Research (2013) reported that in our nation's elementary schools, on average, allocate 20 minutes of the school day on science instruction. This is disturbing for those of us who believe science instruction is important in our schools and students in low SES urban schools need to have high quality, consistent science instruction. Yet, on a brighter note, for Martha, student learning was most important and she was driven to provide her students with an array of inquiry experiences. Martha concluded: "I am passionate about finding the most effective ways of stimulating and sustaining the love of learning in my students." Martha was motivated to teach science and to use inquiry practices during science instruction with her low SES urban students. She believed that they could learn science through inquiry. As evident by Martha's beliefs and practices, how teachers perceive their role as science teachers may have profound effects on what they do. Martha sought to increase students' interest in and experiences with doing science. And what was evident in this study was that she used an array of inquiry-based resources to facilitate the implementation of inquiry practices. Therefore, teacher educators and professional development providers should provide the kinds of inquiry activities that best support teachers' use of inquiry practices in K-12 classrooms as described in the National Science Education Standards (NRC, 1996) and also the Next Generation Science Education Standards (2013). We should construct course work and professional development opportunities for teachers centered on their learning to teach using inquiry methods and provide extended support through developing relationships with school district science curriculum personnel so that teachers can get the reinforcement they need to keep using inquiry once they begin working in their respective schools. Teachers should be supported as they do inquiry such that they develop what Dewey (1910) called, "a mode of intelligent practice and a habitual disposition of mind" (p.124), so that all learners benefit from rich, challenging science experiences, including those in urban low SES schools.

Acknowledgements

The preparation of this manuscript was funded by a grant from the National Science Foundation (NSF, Grant REC-0447676).

References

Abell, S., & Smith, D. (1992). What is science? Pre-service elementary teachers' conception of the nature of science. In S. Hills (Ed.). *Proceedings of the Secondary International and Philosophy of a Science Teaching Conference* (p.11-12). Kingston, Ontario, Canada Queen's University.

Alkove, L., & McCarty, B. (1992). Plain talk: Recognizing positivism and constructivism in practice. *Action in Teacher Education*, *14*(2), 16-22.

Burry-Stock, J. (1999). *ESTEEM instrument.* Western Michigan, University, Kalamazoo, MI: CREATE.

Brand, B. R., & Glasson, G. E. (2004). Crossing cultural boarders into science teaching: Early life experiences, racial and ethnic identities, and beliefs about diversity. *Journal of Research in Science Teaching*, *41*(2), 119-141.

Brink, A.S., & Driscoll, M.E. (1988). *The high school as community centered influences and consequences for students and teacher*. Madison Wisconsin: National Center on Effective Secondary Schools.

Bryan, L. A. & Abell, S. K. (1999). The development of professional knowledge in learning to teach elementary science. *Journal of Research in Science Teaching*, *36*, 121-139.

Dewey, J. (1910). Science as subject-matter and as method. *Science*, 121-127.

Furtak, E.M., Seidel, T., Iverson, H., & Briggs, D.C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching a meta-analysis. *Review of Educational Research*, *82*(3), 300-329.

Haberman, M. (1991). The pedagogy of poverty versus good teaching. *Phi Delta Kappan*, *73*(4), 290-294.

Haggerty, S. (1992). Student teachers' perception of science and science teaching. In S. Hills (Ed) *Proceedings of the Secondary International and Philosophy of a Science Teaching Conference* (p.11-12). Kingston, Ontario, Canada Queen's University.

Hewson, P., & Hewson, M. G. A. (1989). Analyses and use of a task for identifying conceptions of teaching science. *Journal of Education for Teaching*, *15*, 191-209.

Horizon Research, Inc. (2013). *2012 National survey of science and mathematics: Highlights Report*. Chapel Hill, NC. Author.

Huber, R. A., & Moore, C. (2001). A model for extending hands-on science to be inquiry based. *School Science and Mathematics*, *101*(1) 32-42.

Jasalavich, S. (1992). Preservice elementary teachers' beliefs about science teaching and learning and perceived sources of their beliefs prior to their first formal science teaching experience. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Boston, MA. March.

Janpierre, B. (2006.) What teachers report about their inquiry practices. *The Journal of Elementary Science Education*, *18*(1), 57-68.

Kaymakaoglu, S. E. (2018). Teacher's beliefs, perceived, practiced and actual classroom practices in relation to traditional (teacher-centered) and constructivist (learner-centered) teaching. *Journal of Education and Learning*, *7*(1) 31-37.

Kazempour, M., & Amirshokoohi, A. (2014). Transitioning to inquired-based teaching: Exploring science teachers' professional development experiences. *International Journal of Environment and Science Education*, *9*(3), 285-309.

Keys, C. W. & Bryan, L. A. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching*, *38*(6), 631-645.

Lawrenz, F. (1986). Misconceptions of physical science concepts among elementary school teachers. *School Science and Mathematics*, *86*(4), 1213-1214.

Leonard, J. Barnes-Johnson, J, Dantley, S. J. & Kimber, C. (2011). Teaching science inquiry in urban contexts: The role of elementary pre-service teachers' beliefs. *Urban Review*, *42*, 124-150.

Lorsbach, A. (1992). An interpretive study of prospective teachers' beliefs about the nature of science. Paper presented at the annual meeting of the National Association for Research I Science Teaching, Boston.

Lotter, C., Thompson, S., Dickenson, T., Smiley, W. Blue, G. & Rea, M. (2018). The impact of practices teaching professional development model on teachers' inquiry instruction and inquiry efficacy beliefs. *International Journal of Science & Mathematics Education*, *16*(2) 255-273.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.

National Science Research Council. (2011). *A Framework fork-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: National Academy Press.

National Science Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

Nespar, J. (1987). The role of beliefs in the practice of teaching. *Journal of Curriculum Studies*, *19*, 317-328.

Norman, O., Ault, C. R., Nentz, B., & Meskimen, L. (2001). The black white "achievement gap" as a perennial challenge of urban science education: A sociocultural and historical overview with implications for research and practice. *Journal of Research in Science Teaching*, *38*(10), 1101-1114.

O'Laughlin, J. (1990). Evolving beliefs about teaching and learning, the view from Hofstra University: A perspective on teachers' beliefs and their effects. Paper presented at the annual meeting of the American Educational Research Association, Boston.

Opfer, V.D., & Pedder, D. (2011). Conceptualizing teacher professional learning, *Review of Educational Research*, *81*(3), 376-407.

Pajares, M. F. (1992). Teachers' beliefs and educational research: cleaning up a messy construct. *Review of Educational Research*, *62*, 307-332.

Parke, H. M..., & Coble, C. R. (1997). Teachers designing curriculum as professional development: A model for transformational science teaching. *Journal of Research in Science Teaching*, *34*, 773-789.

Pennuel, W. R., & Fishman, B. J. (2012). Large scale science intervention research we can use. *Journal of Research in Science Teaching*, *49*(3), 281-304.

Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. In J. Sikula. (Ed.), *Handbook of research on teacher education* (pp.102-119). New York: Macmillan.

Rist, R. (2017). *The urban school: Factories for failure*. New York, NY: Routledge.

Schwab, J., & Brandwein, P. F. (1996). *The teaching of science of as enquiry. Elements in a strategy for teaching science in the elementary school*. Cambridge, Massachusetts: Harvard University Press.

Stevens, F. I. (1993). Applying an opportunity-to-learn conceptual framework to the investigation of the effects of teaching practices via secondary analyses of multiple-case study summary data. *Journal of Negro Education*, *62*(3), 232-248.

Yin, R. (1989). *Case study research: Design and methods*. Beverly Hills, CA: Sage Publication.

Yin, R. (2015). *Qualitative research from start to finish*. New York, NY: Guilford Publications

ISSN:2149-8504 (online)

Appendix A: Examples of ESTEEM Instrument Items

Please use the indicated ratings to describe your teaching practices and beliefs.

5= (almost always), 4= (often), 3-(sometimes), 2-(seldom), 1-(almost never)

1. Your students are responsible for their own learning. 1 2 3 4 5

2. Your students actively engaged in initiating experiences. 1 2 3 4 5

3. Your students are actively engaged in asking questions throughout class-time. 1 2 3 4 5

ISSN:2149-8504 (online)

Journal of Research in STEM Education

Vol 4, No 2, December 2018, 159-178

RESEARCH REPORT

An Exploratory Cross-Sectional Survey Study of Elementary Teachers' Conceptions and Methods of STEM Integration

Kathryn "Annie Arnone" [a1], Deborah Hanuscin[b]

[a]*Endeavor STEM Education, USA;* [b]*Western Washington University, USA*

Abstract: *Because elementary teachers are typically responsible for teaching all subjects, there is a unique opportunity for integrative approaches to teaching iSTEM Education at the elementary level (Becker & Park, 2011). However, there is a need for professional development if teachers are to be successful in teaching iSTEM Education (NRC, 2011), as elementary teachers may lack strong content knowledge in STEM disciplines (Ginns & Watters, 1995; Trygstad, 2013; Honey et al., 2014; Fulp, 2002; Ma, 1999; Hanover, 2012). Elementary teachers are prepared as generalists--they take few courses in STEM content, and experiences with iSTEM Education in their teacher preparation programs are rare (Fulp, 2002). Beyond the need for professional development related to STEM content knowledge, however, we know very little about the unique needs of elementary teachers regarding instructional approaches to iSTEM Education. This study examines and describes the ways in which elementary teachers conceptualize iSTEM Education and the integrative approaches they use when teaching STEM content, with the intent to inform the development of elementary specific iSTEM Education professional development.*

Keywords: STEM, integration, iSTEM, integrated STEM, elementary STEM

Introduction

According to the President's Council of Advisors on Science and Technology (2010), "the success of the United States in the 21st century will depend on the ideas and skills of its population" (p. 5). Science, Technology, Engineering, and Mathematics (STEM) Education works to develop students who have the technical skill-set necessary to boost the United States back into the global economic competition (PCAST, 2010). While STEM Education lacks a formal, universally accepted definition, there is an overwhelming consensus regarding the importance of the need to develop STEM literate individuals. Trygstad (2013) stated "A new workforce of problem-solvers, innovators, and inventors who are self-reliant and able to think logically is one of the critical foundations that drive innovative capacity" (p. 1). These national reform documents all call for increased STEM curricula and instruction to increase the number of students going into STEM fields (Ring et al., 2017) and elementary teachers are on the front lines in tackling the challenge.

To address the need for STEM literate individuals, elementary teachers have been charged with building the foundation for this STEM workforce. However, there is little research that can inform the design of iSTEM professional development to address the unique challenges elementary teachers face when teaching iSTEM Education. The findings from the exploratory cross-sectional survey study intend to describe current conceptions and practices of elementary teachers in order to provide insight into the unique professional development needs of elementary teachers in iSTEM Education.

[1] Corresponding author. *Endeavor STEM Education, Contact: 573-310-1013,* E-mail: karnone@us-satellite.net

Arnone, K. A., & Hanuscin, D. (2018). An Exploratory Cross-Sectional Survey Study of Elementary Teachers' Conceptions and Methods of STEM Integration *Journal of Research in STEM Education*, *4*(2), 159-178.

ISSN:2149-8504 (online)

Review of Relevant Literature

The present study is informed by literature related to defining STEM, integrating STEM, and preparing teachers to implement STEM.

Defining STEM Education

Despite the consensus among the education community regarding the importance of STEM Education, there isn't a universal consensus on a definition (Shernoff et al., 2017), or agreement that one is needed. A simple search in the literature for STEM Education yields an array of varying ideas for defining STEM. When comparing these definitions, several patterns emerge. First, STEM Education is conceptualized in three distinct ways-- as an approach to learning, as an approach to teaching, and as a philosophical stance toward education. Across these three distinctions, however, there are some commonalities. For example, the need for providing opportunities for students to apply their knowledge is prevalent among many definitions, as well as the focus on integration.

Integrative approaches are defined as "approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects (Sanders, 2009, p. 21)." Proponents of iSTEM Education agree that an integrative approach is a key component of effective iSTEM Education instruction (Johnson et al., 2015; Nadelson et al., 2013); but there is no consensus among the education community regarding the method of integration (Means et al., 2008), and there are a variety of ways in which STEM content can be integrated (Becker & Park, 2011). Furthermore, there are varying depths by which STEM content can be integrated (Nathan et al., 2013) and there are empirical studies supporting the use of curriculum that promotes integrated STEM Education experiences (Wang, et al., 2011). The current literature, however, focuses primarily on the integration of math and science, rather than on integration across all STEM disciplines (Heil et al., 2013).

Preparing Elementary Teachers to Integrate STEM

Elementary classrooms have different affordances for integration than secondary educators as there is flexibility in the elementary curriculum that can support new approaches for teaching iSTEM Education (Nadelson et al., 2013). Furthermore, elementary teachers are typically responsible for teaching all subjects, so there is a unique opportunity for integrative approaches to teaching iSTEM Education at the elementary level (Becker & Park, 2011). Yet, there are few elementary specific iSTEM Education professional development opportunities (as opposed to specific to individual disciplines of STEM) (Hanover, 2012). Both research and professional development on iSTEM Education are often grouped together in a K12 bundle and don't distinguish between the levels of elementary or secondary education (Hanover, 2012) where the affordances for integration are quite different.

Need for the Study

Though the elementary classroom presents unique affordances for iSTEM Education, we currently know very little about how elementary teachers conceptualize iSTEM, which types of integration elementary teachers are using in their instructional approaches to iSTEM Education, and the unique needs that elementary teachers may have when it comes to iSTEM Education professional development. Considering teacher beliefs and perceptions regarding integrative approaches among STEM content as teacher professional development programs work to develop teacher thinking and practice is important as both teacher attitudes and perceptions "drive classroom actions and influence the teacher change process" (Richardson, 1996, p. 102). To address the gaps in the literature revealed above, this study examines the conceptions and integrative practices of elementary teachers in iSTEM Education and explores difficulties elementary teachers face when teaching iSTEM Education that can shed light on their specific professional development needs.

ISSN:2149-8504 (online)

Theoretical Framework Guiding the Study

This study is framed by the iSTEM Education framework by Honey and colleagues in the report STEM Integration in K-12 Education: Status, Prospects and an Agenda for Research (2014). This framework includes four main features: (a) goals of integrated STEM Education, (b) outcomes of integrated STEM Education, (c) the nature and scope of integrated STEM Education, and (d) implementation of integrated STEM Education (p. 31). This framework is intended to provide researchers with the vocabulary to "identify, describe, and investigate specific integrative STEM initiatives…" (Honey et al., 2014, p. 31).

The present study also uses the integration approaches described by Davison, Miller, and Metheny (1995) as an analytical framework. Davison et al. (1995) described five types of integration specifically related to math and science. However, this framework can easily be applied to STEM disciplines more broadly. These five methods include: (a) Discipline Specific Integration (b) Content Specific Integration (c) Process Integration (d) Methodological Integration and (e) Thematic Integration. Like many integrative models, however, these approaches are not grounded in studies of actual teachers' integrative practices but are merely presented as options for integration. Thus, the present study will provide an empirical test of the framework.

The study described in the following section is guided by the following research questions:

1. To what extent are elementary teachers' prepared to implement iSTEM Education?
   - What are elementary teachers' perceived levels of preparedness to implement iSTEM Education?
   - What is the nature of iSTEM Education opportunities in which elementary teachers have participated?
2. In what ways do elementary teachers approach iSTEM Education in their lesson plans?
3. How do elementary teachers conceptualize iSTEM Education?
   - What learning goals do elementary teachers have for students as part of their iSTEM Education lessons?
   - What do teachers see as the benefits of students learning about iSTEM Education (outcomes)?
   - What is the nature and scope of teachers' integration of STEM disciplines?
   - What instructional designs, supports, and adjustments to the learning environment do teachers utilize when integrating STEM content?

Methodology

This qualitative study used an exploratory cross- sectional survey design to examine the variations in the ways elementary teachers conceptualize and design iSTEM Education instruction. A cross-sectional survey approach was appropriate for this study as I intended to reveal the conceptualizations and practices of elementary teachers regarding iSTEM Education at a single point in time (Creswell, 2013). An exploratory study was appropriate because of the lack of detailed preliminary research in this area and because I desired to show that further research is needed (Stake, 1995). The intent is to provide insight into teachers' conceptions that can inform further research in iSTEM Education, specifically in regards to the unique professional development needs of elementary teachers.

ISSN:2149-8504 (online)

Context of the Study

Participants

Participants in this study were certified classroom elementary teachers in a Midwestern state. Participants were collected using a convenience sample and snowball sampling via email, social media, internet postings, and word of mouth. Twenty-nine teachers responded initially, submitting responses to an online survey as well as an iSTEM Education lesson plan. The twenty-nine teacher participants in this study taught grades Kindergarten through 5th grade. 38% taught Kindergarten through second grade, while 62% taught third through fifth grade. 45% of teachers taught in an urban area while 55% taught in a rural area. 27% of teachers had 1-5 years teaching experience, 28% had 6-10, 28% had 11-15, and 17% had 16 or more years of teaching experience.

Data Sources and Analysis

The data collected included a survey, an iSTEM Education lesson plan, and an interview. Research questions 1 and 2 were answered by examining survey and lesson plan data for the entire sample, whereas research question 3 was answered by interviewing a purposeful subsample of participants in-depth.

Survey

Stage one of data collection for this study began with a Teacher Survey. The intent of this survey was to reveal the teachers' ideas regarding iSTEM Education, their level of teaching experience in general and specific to iSTEM Education, and the types of professional development experiences teachers have had related to iSTEM Education. The survey included demographics and questions that addressed the instructional resources they use and the professional development they have had specifically related to STEM Education. Responses to the survey questions assisted in determining where the teacher would fall on the beginner to expert continuum and was used to help select cases for the purposeful sample.

All teachers in the population sample completed a teacher survey using the Jotform online survey tool. Teacher participants were categorized into groups based on their responses to survey questions to provide insight on the range of experience and knowledge in iSTEM Education of the population sample. I then analyzed each survey by identifying which ones included the themes that best addressed the research questions for this study. After careful review of the survey results, directed content analysis was conducted to determine the frequency of concepts and ideas that arose in the data (Petocz & Newbery, 2010) and to determine a purposeful sample to interview.

iSTEM Education Lesson Plan

Lesson plans are essential forms of data as they reflect outcomes teachers have for their instruction and were chosen for this study as there was a desire to learn more about teacher instructional practices (Sias et al., 2016). Lesson plan submission requirements were as follows a) the lesson must be a lesson the teacher has previously taught b) the lesson is written by the teacher (i.e. not a scanned copy of a lesson included in a curriculum book, though teachers may draw on lessons created by others) and c) the submission includes all additional items (worksheets, rubrics, etc.). While not all teachers may have experience in creating iSTEM lesson plans specifically, they all should have had experience with creating lesson plans for their classroom. These iSTEM Education lesson plans were intended to provide an example of the extent to which these teachers are integrating STEM content in their iSTEM Education lesson designs, and helped determine which participants should be interviewed in Stage 2 of the data collection process.

Lessons were then sorted by integration methods following Davison and colleagues' (1995) five types of integration (a) Discipline Specific Integration, (b) Content Specific Integration, (c) Process Integration, (d) Methodological Integration and (e) Thematic Integration. Each lesson was sorted based on the information provided in the lesson plan. A few issues arose as not all lessons included exactly the same elements as no general lesson plan template was provided. Teachers were allowed to submit lessons in whichever way they

ISSN:2149-8504 (online)

desired. Assumptions were made at times as to what subjects were being used as no standards or objectives were explicitly written. Some lessons also claimed to include elements such as engineering, but upon further analysis, it was found that they did not.

Interviews

Five teachers were chosen as the purposeful sample and all participated in a follow-up phone interview, allowing for further clarification of instructional choices as well as descriptions of conceptualizations and teaching practice. These teachers were chosen as they all used a different integrative approach in their iSTEM Education Lesson Plan and represented a range in multiple categories (grade level taught, years of teaching experience, experience in STEM, etc.). In this manner, their responses could illustrate the range of ways in which teachers conceptualize iSTEM education across a variety of integrative approaches.

Integration methods used in iSTEM Education lesson plan submissions of the purposeful sample included Methodological Integration, Thematic Integration, Content Specific Integration, Process Specific Integration, and No Integration. This subset of teachers was chosen to better understand the range and types of integration used by elementary teachers when designing iSTEM Education instruction.

All interviews were transcribed for analysis, which began with open-coding of hard copies of the transcripts. A highlighter color was assigned for each of the research questions, and transcripts were examined line-by-line to identify excerpts relevant to each question and assign codes. Intercoder agreement was established through analysis of a sample of data conducted by myself and a peer debriefer. Using the Teacher Interview responses to the question "Why is it important for students to learn STEM?" the peer debriefer and I used open coding for first-level coding and then directed content analysis with axial coding for second-level coding, to independently read and code themes by hand. These themes were both predetermined (integrative approaches in the iSTEM lesson plans) and those that emerged from the data (in all data sources). We then came together to compare codes and themes to check for intercoder agreement. Any differences were discussed, and changes in coding were made as agreed upon by coders.

Once coding was complete, codes for each research question were entered into an Excel workbook with a separate tab for each question/code set. Frequencies of codes across all five participants were noted to assess the prevalence of the codes across the entire data set. Codes were then grouped into categories based on similarities and themes that emerged. Themes were then examined in relation to the research questions, and the absence of particular themes was also noted.

Results

The results are presented in order of the research questions, beginning with information about elementary teachers' preparedness to implement iSTEM, the methods by which they approach STEM integration in their lessons, and how they conceptualize iSTEM education. Results should be interpreted within the limitations of this study, which include the small sample size of teacher participants. Teachers were self-selected, and it is possible that teachers who chose to participate in the study are biased and are more "pro-STEM" than their colleagues who were not involved in the study. Additionally, the sample is limited to elementary teachers in one state, and the findings of this study may not apply to all elementary teachers.

Experience Level with STEM

First, teachers self-placed themselves on a STEM Education experience continuum describing their previous work in STEM Education that ranged from Beginner to Advanced. 69% identified as Beginners, 11% identified as Somewhat Experienced, 17% identified as Experienced, 3% identified as Somewhat Advanced, and 0% identified as Advanced. Placements on the continuum were intended to provide a ranking of teacher participants in regard to their current experience in STEM Education. These self-rankings were not necessarily made based on similar understandings of 'STEM Education', and some teacher participant placements did not

ISSN:2149-8504 (online)

necessarily match their actual level of experience, based on the analysis of their lesson and interview. During interviews, some teacher participants who identified themselves at a higher level of experience ended up indicating they would change their ranking to a lower level. Regardless of the actual accuracy of continuum placements by teacher participants, these "rankings" allowed us to see where teachers thought they were on the STEM Education experience continuum, based on the way they conceptualized iSTEM Education at the time.

Participation in STEM Professional Development

Next, teachers reported on the hours of professional development they have experienced in the past two years related to STEM Education. 38% reported 0 hours, 38% reported 1-25 hours, 10% reported 26-50 hours, 4% reported 51-100 hours, and 10% reported more than 101 hours. Of the professional development hours reported, teachers identified the number of those hours that were elementary specific experiences versus those that were presented in a K12 bundle. 38% identified 0 hours of elementary specific STEM professional development, 41% identified 1-25 hours, 10% identified 26-50, 4% identified 51-100, and 7% identified more than 101 hours of elementary specific professional development.

The majority of elementary teachers in this study have not participated in many hours of STEM related professional development. Some teachers who did report higher amounts of STEM-related professional developed, mentioned that they considered individual subject area professional development experiences (science, technology, or math professional development) as part of their hours of STEM-related professional development, even though the experience did not focus on integrated STEM Education.

Teachers were also asked to rate their satisfaction with the STEM Education professional development they had attended over the past two years. 27% were Not Satisfied, 14% were Somewhat Satisfied, 45% were Satisfied, and 14% were Very Satisfied. Some teachers indicated they were satisfied with the STEM Education professional development they had attended, even though they had reported attending zero hours of STEM Education specific professional development. Teachers who expressed this stance towards STEM Education professional development were generally not concerned with the fact they hadn't had any specific STEM professional development. They were either uninterested in receiving professional development in STEM Education or they expressed that they were unaware that they needed it.

Finally, teachers rated their satisfaction with the availability of STEM Education professional development. 45% were Not Satisfied, 7% were Somewhat Satisfied, 41% were Satisfied, and 7% were Very Satisfied. Some teachers indicated they might get more STEM Education professional development if they asked their district, but they were unaware of any opportunities that were readily available to them.

Many participants in this study were mostly satisfied (45%) with the STEM Education professional development they attended, but most (45%) were unsatisfied with its availability. While participants expressed a general satisfaction with the STEM Education professional development they had attended, the specific nature of those experiences are unclear. Interviews with a sample of participants was intended to provide more detailed information about teachers' satisfaction with the quality and availability of STEM PD opportunities.

Teachers' Approaches to Integrating STEM

Analysis of teachers' lessons revealed a wide variety of conceptions, and approaches to STEM education. Considering the Six Essential Features of Effective STEM Integration (Johnson et al., 2015), teachers in this study did not include and were not primarily concerned with the majority of the features considered to be essential.

For example, meaningful learning and engaging contexts (feature 1) was either not included or was surface level. Engineering design challenges were almost missing entirely (feature 2) and explicit standards addressed in lessons (feature 4) specific to math and science were weak or missing. Finally, most teachers did not focus on providing learning experiences where students had the opportunity to deepen their conceptual knowledge (feature 5). Teachers tended to address feature 3 (allowing mistakes) and feature 6 (collaboration)

ISSN:2149-8504 (online)

in their lesson plans.

An analysis of lessons using Davidson et al.'s framework also showed variation in how teachers integrated STEM. First, the majority of the lessons submitted from the population sample (48%) fell into the category of No Integration; meaning the lesson was primarily one subject only. For example, one teacher submitted a lesson plan with the goal of students being able to identify area and perimeter of a square and a rectangle using a formula. Math was the only subject represented.

The next largest proportion (21%) of teachers submitted lesson plans that were Process Integration; meaning they posed a problem and used science processes and math standards to find answers. For example, one teacher submitted a lesson plan that asked students construct a bridge out of toothpicks and gum drops. Students create and record multiple types of bridges, focusing on which shapes of bridges could hold the most weight. Students test and collect data to ultimately try and determine which shape bridge is best for holding the most weight.

The third largest proportion (17%) of teachers submitted lesson plans that used Content Specific Integration; meaning they used at least one standard from one subject and another standard from another subject. For example, one teacher submitted a lesson plan using one standard from science and one standard from math. This lesson had students investigating friction by pulling water bottles attached to spring scales across various surfaces and calculating the averages of multiple pulls across each surface in Newtons.

The two smallest categories were Thematic Integration and Methodological Integration. Only 7% of teachers submitted lesson plans that used Thematic Integration; meaning all content areas focused on a theme. For example, one teacher used "pumpkins" as the theme of her lesson, and included activities such as estimating the number of pumpkin seeds inside the pumpkin, painting the pumpkin, and reading and writing stories about pumpkins. Only 7% of teachers submitted lesson plans that were Methodological Integration; meaning they used inquiry, the learning cycle, discovery, etc. to build knowledge using science and math. For example, one teacher submitted a lesson plan that used the 5E learning cycle where students used science, engineering, and math to learn about the water cycle. Students progressed through each learning sequence, engaging in activities that helped them discover how the water cycle works and then progressed into designing solutions to solve water pollution problems.

No teachers (0%) submitted lessons that were Discipline Specific Integration; meaning they pulled standards/content from different fields in the same subject (i.e. Algebra and Geometry or Biology and Geology). That is, teachers typically stuck to a specific topic within a discipline, as opposed to focusing on cross-cutting concepts within a discipline.

Interviews with the purposeful sample of teachers sheds light on the nature and scope of teachers' integration within each category, the learning goals they defined for students, their perceived benefits of teaching STEM, and how they conceptualize and enact STEM. These data are presented in the form of vignettes (see Appendix A) describing the teacher participants and the integrative approach their iSTEM Education Lesson Plans used.

Discussion

The purpose of this study was to examine and describe the ways in which elementary teachers conceptualize iSTEM Education and the integrative approaches they use when teaching STEM content, with the intent to inform the development of elementary specific iSTEM Education professional development. The findings of this study are discussed in light of the research questions in the sections that follow.

ISSN:2149-8504 (online)

To what extent are elementary teachers prepared to implement iSTEM Education?

Teachers in this study were generally unprepared to implement iSTEM Education, as evident by the lack of STEM Education specific professional development attended as reported by teacher participants. This is not surprising considering that elementary teachers lack content knowledge in STEM content areas (Trygstad, 2013; Honey et al., 2014; Fulp, 2002; Ma, 1999; Hanover, 2012) and receive little preparation in these areas during their teacher preparation programs (Fulp, 2002).

An area that is surprising among the data, is how elementary teachers are seeking out iSTEM Education opportunities and materials on their own due to the lack of support in the area provided by their school or district. Some teachers are using their personal resources to learn how to teach iSTEM Education by writing grants and attending conferences, while others rely solely on those experiences provided by their district or what they can find on the internet. Furthermore, the experiences provided by the districts related to iSTEM Education, tend to be focused on individual subject-specific resources with "STEM" iPad applications and websites used to enhance a lesson. This plays into the idea that iSTEM Education, like technology (Williams, 2011), is being used as a tool to enhance other subjects, rather than a subject of its own.

To some in the study, iSTEM Education is just another "thing" that teachers are required to learn about, but has little effect on their daily teaching practice. However, to others, iSTEM Education is meaningful and they desire assistance in learning how to adjust and modify their teaching practice in a way that is reflective of effective iSTEM Education.

In what ways do elementary teachers approach iSTEM Education in their lesson plans?

Teachers in this study struggled with how to approach designing iSTEM Education lesson plans. Lesson plans were vague, underdeveloped, scattered, or inappropriate for teaching the desired objective. This is possibly indicative of how much time in general elementary teachers are spending on iSTEM Education. They aren't devoting much time in the classroom to iSTEM Education so they aren't taking the time it takes to develop quality iSTEM Education lessons. The reasons why could be numerous and each participant may fall into more than one category.

Perhaps teachers submitted these types of lesson plans because they didn't have time to find anything else. Most teachers reported the lessons they submitted were pre-made so teachers weren't developing them from scratch for this study. Many also reported using websites where they could quickly find a lesson and use it in their classroom.

Perhaps teachers submitted these types of lesson plans because they truly don't know how to integrate and this was their best guess. It is interesting to consider how representative these lessons are of elementary teachers' understanding and ability to create iSTEM Education lessons. For example, teachers indicated that math was difficult to integrate and very few of them submitted lesson plans that integrated math. When teachers did try to integrate, some of their lessons included more standards and objectives than what would seem feasible for moving students towards mastery.

Finally, perhaps teachers submitted these types of lesson plans because they really did represent the way they conceptualized iSTEM Education at that particular moment. Teachers in this study focused on student engagement and making learning fun for their students so many of their lessons focused on being fun and engaging without a focus on content.

How do elementary teachers conceptualize iSTEM Education?

Teachers in this study appear to have general ideas regarding their role as the teacher when teaching iSTEM Education. Teachers see themselves as guides or facilitators and focus on making sure they give their students some independence in their learning. However, these ideas are underdeveloped, and there is a much larger emphasis on students being independent and self-guided than there is on content mastery.

ISSN:2149-8504 (online)

Second, there is little consensus among teachers regarding what is or should be taught in iSTEM Education. Some teachers felt a STEM lesson had to include all four subjects represented in the acronym (science, technology, engineering, and math) while others felt their STEM lesson could include all subjects. Additionally, the nature of the activities described by the teachers show differences in their overall approach to teaching iSTEM Education. For example, utilizing the teaching orientations as described by Magnusson, Krajcik, and Borko (1999), teachers showed multiple orientations to teaching iSTEM Education, but all of them fell into the categories of Activity Driven, Discovery, Project-based, and Guided Inquiry. Sidney and Cassie were primarily Activity Driven, though Cassie also had qualities of Discovery and Sidney had qualities of Project-based. Laura, Kim, and Mary were all primarily Guided Inquiry.

There is some consensus among teachers as to what students should be doing in iSTEM Education. Teachers expressed that students should be working with materials and participating in hands-on activities. Students should have opportunities to create, design, and build and their classroom environment should be such that students are okay with making mistakes.

Notably, teachers in this study differed in how they viewed technology as part of iSTEM Education. Teachers, for the most part, did not express ideas about technology in ways beyond using instructional technology (iPads and other electronic devices). Some teachers commented that they were aware that technology didn't have to be an electronic device. However, their representation of technology in their interviews and lesson plans expressed their dependency on electronic devices and "gadgets" to satisfy their technology integration. Most teachers used technology as a tool to enhance STEM lessons as opposed to focusing on specific technology skills or concepts.

Teachers also fluctuated on their understanding of the STEM acronym. Some understood the acronym to be STEM while others were adamant it was (or believed it should be) STEAM, integrating the Arts into the acronym. Not surprisingly, another area of mismatch appears when comparing teachers' definitions of STEM Education. Just like the rest of the education community, there was no consensus among teachers in the study regarding what STEM Education is and is not. Teachers had ideas, but most were underdeveloped, misguided or incomplete.

What learning goals do elementary teachers have for students as part of their iSTEM Education lessons?

The primary goal teachers expressed for their iSTEM Education lessons was problem-solving. Teachers commented on how students needed to be able to be good problem solvers for future careers and everyday life. Teachers felt problem-solving was important, regardless of whether or not the problem was authentic or contrived. Teachers also had a strong desire to use iSTEM Education as a way to teach students to be independent and self-guided. Additionally, teachers placed a large amount of importance on using iSTEM Education to boost student communication skills through collaboration, team building, and sharing of ideas. Some teachers described their use of iSTEM Education lessons as primarily "ice breakers" or "fillers" when they had a little extra time to "do something fun." Teachers had no concern about meeting standards or objectives during these lessons but rather desired their students to get to know each other and learn to work together and share their ideas.

Building on the previous idea, few teachers had an overall concern about mastery of content or skills as a learning goal. Teachers were more concerned with collaboration and communication as opposed to specific learning objectives or better conceptual understanding of content. In fact, some teachers were more concerned with their lessons being "fun" and "engaging" than they were on the content being discussed. They liked that iSTEM Education lessons that they had observed seemed fun and engaging for kids, so that was their primary reason for using them. Finally, while some teachers included some elements of engineering practices in their lessons and descriptions of iSTEM Education, most were underdeveloped. For example, the idea of making models and prototypes was the primary way of including engineering in a lesson. The idea was that as long as students were making building or making a model, they were engaging in engineering. Teachers had some

ISSN:2149-8504 (online)

understanding of what engineering entails but it was surface level and not necessarily representative of what engineers actually do.

What do the teachers see as the benefits of students learning about STEM (outcomes)?

Overall, teachers had very little to share regarding their thoughts on how iSTEM Education would be beneficial for their students. Most of them expressed they had heard about it and felt it was important but just didn't feel like they knew enough about it to really have much of an opinion beyond their surface level understanding of iSTEM Education. However, teachers tended to somewhat agree on the idea of there being academic benefits to students learning about and participating in iSTEM Education. Teachers also expressed that engaging in iSTEM Education enhanced retention. Teachers discussed how student engagement in iSTEM Education aided students in retaining information that they would be able to recall and apply later, be it later that school year or more long-term such as later in life. Teachers focused on potential jobs that might require skills promoted in iSTEM Education. For example, teachers expressed that iSTEM Education helps students become well-rounded or well-versed in multiple areas, making them capable of doing more than one thing. Teachers felt this was an important skill-set for students to have, to be good at more than one thing, because jobs now and in the future will demand that capability.

Last, some teachers felt a benefit to teaching iSTEM Education was because it was more engaging for students and therefore aided in behavior management. Teachers shared how they had students who had difficulty sitting still or behaving through more traditional methods of teaching but using more "STEM-based" lessons helped these students to be more engaged and produce better quality work.

What is the nature and scope of teachers' integration of STEM disciplines?

When it comes to integration, the number one area of concern for teachers was math. Teachers expressed that they felt math was the most difficult subject to truly integrate and struggled to figure out how to do so in their classrooms. Some felt like math was perhaps one of those subjects that had times when the concepts just needed to be taught separately, such as memorizing multiplication facts. Some teachers shared they would have counting or numbers involved in a math lesson, but there really weren't any explicit math concepts being taught.

Considering the Six Essential Features of Effective STEM Integration (Johnson et al., 2015), teachers in this study were primarily focused on feature three and feature six. Feature three indicated that effective STEM integration provides opportunities for students to make and learn from mistakes. Teachers in this study indicated they desired for their students to be able to make mistakes and tried to create a classroom environment that was conducive for students to take risks in their learning. Feature six emphasizes teamwork and collaboration, which many teachers emphasized as being an important reason for teaching iSTEM lessons.

Many teachers commented that they don't specifically teach iSTEM Education on a regular basis because they are not in a school or district where iSTEM Education is a particular focus. Because of this, they say they don't really have much in the way of professional development offerings and therefore lack the knowledge and skills they need to be able to integrate and teach iSTEM Education. All teachers commented on their focus of integrating reading and writing in everything they teach. While there was nearly universal agreement that subjects should not be taught in isolation, the degree to which integration should take place and what subjects should be integrated was unclear.

Finally, teachers revealed that very little time was devoted to iSTEM education in a typical school day. Some teachers had separate STEM times during the day or after school clubs that focused on iSTEM Education. However, most teachers did not teach iSTEM Education consistently or as a normal part of their typical school day.

ISSN:2149-8504 (online)

What instructional Designs, supports, and adjustments to the learning environment do teachers utilize when integrating STEM?

When it comes to iSTEM Education supports, teachers relied heavily on the internet and technological applications. Websites such as Pinterest and Teachers Pay Teachers were cited by all teacher participants as places they go to find iSTEM Education lessons. Additionally, applications such as Google Apps and Twitter were cited as iSTEM Education supports as well.

Aside from the technology supports for iSTEM Education teachers also indicated they relied heavily on teachers in their own building for support. Colleagues in their building who are either grade level partners, other classroom teachers in their building, or specialist teachers were all referenced as sources for iSTEM Education supports from participating teachers. No teachers mentioned having any iSTEM Education specific professional development, materials, or resources provided for them by their district for iSTEM Education. Teachers lack access to quality iSTEM Education specific resources and when they did find some they felt was worthwhile, they had to take it upon themselves to attain it (i.e. pay for it out of their own pocket, spend their free time at home working on a grant to get materials, etc.).

Considering the elementary teachers' unique opportunity to integrate (Becker & Park, 2011), a surprising finding of this study is that teachers' lessons were primarily one subject only and many lacked components such as standards and objectives. While this may be an artifact of the shorthand of 'lesson plans', nonetheless the majority of lessons fell into the category of "No Integration" within Davison and colleagues' framework (1995). While it appears this is somewhat related to how teachers conceptualize STEM, it might also reflect lack of knowledge for how to integrate, or constraints of their mandated curriculum.

Implications

The results of this study illustrate that there is much work to be done in helping teachers create quality iSTEM Education lesson plans that integrate in a way that is reflective of the Essential Features of Effective iSTEM Education Integration. Despite highlighting teachers' enthusiasm and interest in iSTEM, the examples presented in this study revealed a multitude of common difficulties elementary teachers faced regarding their conceptualization and implementation of iSTEM Education. These common difficulties have implications for the design of professional development opportunities for elementary teachers in iSTEM Education in that they help to address the urgency to understand the obstacles educators face when creating and conducting integrated STEM experiences (Shernoff et al., 2017). I have identified the common elementary teacher difficulties when attempting to integrate iSTEM Education along with specific recommendations for professional development in Table 1.

ISSN:2149-8504 (online)

Table 1.
Teacher Difficulties Identified and Recommendations for Professional Development

Identified Common Teacher Difficulties	Recommendations for Professional Development
Teachers have general ideas regarding their role when teaching iSTEM Education, but these ideas are underdeveloped.	Teachers need to engage in discussions and view videos of iSTEM Education in action to get a more clear idea of the teacher and student roles in iSTEM Education.
Teachers struggle to decide what is or should be taught in iSTEM Education and get stuck on the subjects represented in the STEM acronym.	Teachers need to engage in activities and discussions aimed at illustrating what should be taught within iSTEM Education.
Teachers struggle with determining what iSTEM Education looks like at the elementary level.	Teachers need to see images of iSTEM Education and at the elementary level through videos and sample lesson plans.
Teachers saw technology in iSTEM Education primarily as using electronic gadgets.	Teachers need to consider different ways technology can be integrated to not only enhance other subjects but to build technological skills specifically.
Teachers saw iSTEM Education as something targeted primarily for gifted students or those who were good at math.	Teachers need to engage in activities and discussions that challenge this misconception to develop an understanding of STEM for all.
Teachers struggled to define iSTEM Education beyond knowing the subjects represented in the STEM acronym.	Teachers need to examine, compare, contrast, and develop their own definitions of iSTEM Education.
Teachers expressed their primary goal for iSTEM Education lessons was for problem-solving.	Teachers need to engage in activities and discussions on problem-solving strategies and to identify the various types and how they work in engineering.
Teachers use iSTEM lessons as 'ice breakers' or for team building activities. Not focused on mastery of content or skills.	Teachers need to engage in lesson plan analysis tasks to aid in learning how to develop iSTEM lesson plans that have a purpose and are focused on content.
Teachers had some idea about what engineering is in general but lacked knowledge on what it would look like at the elementary level.	Teachers need to engage in an analysis of various engineering design cycles and see images of what engineering what look like at the elementary level.
Teachers struggled to understand the benefits of iSTEM Education beyond future job skills and behavior management.	Teachers need to engage in activities where they are exposed to positive and negative rationales for iSTEM Education to allow them to develop an understanding of the benefits of iSTEM Education.
Teachers struggled with integrating subjects, particularly math, beyond surface level and nearly all expressed great desire to have professional development in integration.	Teachers need to engage in activities and discussion focused on integration methods of various subjects in iSTEM Education, particularly math.
Teachers struggled to identify quality resources for teaching iSTEM Education lessons and depended on websites such as Pinterest and Teachers Pay Teachers.	Teacher need to critique lessons and units of iSTEM Education to learn how to determine quality iSTEM Education lessons.
Teachers struggled with the idea of creating their own iSTEM Education lesson plans but expressed the desire to learn.	Teachers need to create iSTEM Education lessons and units with guidance that are applicable to the grade level they teach.
Teachers struggled to find professional development in elementary iSTEM Education as their schools and/or districts did not have a STEM focus.	Teachers need an online course so all teachers, regardless of location, have access to iSTEM Education professional development.

Based on the common teacher difficulties identified above, professional development providers will have a clearer understanding of the unique professional development needs for elementary teachers in iSTEM Education. Furthermore, the identification of these common difficulties may inform the design of new professional development programs and experiences that specifically address and support the needs of elementary teachers in their pursuit towards teaching quality iSTEM Education in their classrooms. These professional development experiences are vital if elementary teachers are to be expected to teach iSTEM Education (NRC, 2011).

To move the field forward, future studies should focus on the way in which elementary teachers integrate content in their teaching practice in general, as well as regarding iSTEM Education specifically. Next, future studies should attempt to work towards identifying best practices and methodologies for teaching iSTEM Education at the elementary level. Finally, future studies should investigate the effectiveness of the professional development experiences provided for elementary teachers in iSTEM Education.

References

Ansberry, K., & Morgan, E. R. (2010). *Picture-perfect science lessons: Using children's books to guide inquiry*. NSTA Press.

Becker, K., & Park, K. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. *Journal of STEM Education: Innovations and Research*, *12*(5/6), 23.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Davison, D. M., Miller, K. W., & Metheny, D. L. (1995). What does integration of science and mathematics really mean? *School Science and Mathematics*, *95*(5), 226-230.

Fulp, S. (2002). The status of elementary school science teaching. Chapel Hill, NC: Horizon Research. Retreived from http://www.horizon-research.com/horizonresearchwp/wp-content/uploads/2013/04/elem_science.pdf

Hanover Research (2012) Best Practices in Elementary STEM Programs. Washington D.C.: Retreived from http://school.elps.k12.mi.us/ad_hoc_mms/committee_recommendation/4.pdf

Heil, D., Pearson, G., & Burger, S. (2013). Understanding Integrated STEM Education: Report on a National Study. Presentation at the 120th ASEE Annual Conference and Exposition, Atlanta, GA.

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. National Academies Press.

Johnson, C. C., & Sondergeld, T. A. (2015). Need for Professional Development to Change Practice. *STEM Road Map: A Framework for Integrated STEM Education.*

Johnson, C. C., Peters-Burton, E. E., & Moore, T. J. (Eds.). (2015). *STEM Road Map: A Framework for Integrated STEM Education. Routledge.*

Ma, L. (1999). "Teachers' Subject Matter Knowledge: Profound Understanding Of Fundamental Mathematics." *Knowing and teaching elementary mathematics: Teachers' understanding of fundamental mathematics in China and the United States*. Mahwah, NJ: Lawrence Erlbaum Associates.

Magnusson, S. K., & Krajcik, J. J. & Borko, H.(1999). Nature, sources and development of pedagogical content knowledge for science teaching. Gess-Newsome & Lederman (Eds.), *Examining Pedagogical Content Knowledge: The Construct and Its Implications for Science Education.* Dordrecht: Kluwer Academic Publishers.

Means, B., Confrey, J., House, A., & Bhanot, R. (2008). STEM high schools: Specialized science technology engineering and mathematics secondary schools in the US. *SRI International*, 25.

Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers. *The Journal of Educational Research*, *106*(2), 157-168.

Nathan, M. J., Srisurichan, R., Walkington, C., Wolfgram, M., Williams, C., & Alibali, M. W. (2013). Building cohesion across representations: A mechanism for STEM integration. *Journal of Engineering Education*, *102*(1), 77-116.

ISSN:2149-8504 (online)

National Research Council. (2011). *A framework for k-12 science education practices, cross-cutting concepts, and core ideas*. Washington, DC: National Academies Press.

President's Council of Advisors on Science and Technology (US). (2010).*Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future: Executive Report*. Executive Office of the President, President's Council of Advisors on Science and Technology.

Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. *Handbook of research on teacher education*. Macmillan Library Reference USA, Simon & Schuster Macmillan, 1633 Broadway, New York, NY 10019.

Ring, E. A., Dare, E. A., Crotty, E. A., & Roehrig, G. H. (2017). The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *Journal of Science Teacher Education*, *28*(5), 444-467.

Sanders, M. (2009). STEM, STEM Education, stemmania. *The Technology Teacher*, *68*(4), 20-26.

Sias, C. M., Nadelson, L. S., Juth, S. M., & Seifert, A. L. (2016). The best laid plans: Educational innovation in elementary teacher generated integrated STEM lesson plans. *The Journal of Educational Research*, 1-12.

Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education*, *4*(1), 13.

Stake, R. E. (1995). *The art of case study research*. Sage.

Trygstad, P. J. (2013). *2012 National Survey of Science and Mathematics Education: Status of elementary school science*. Chapel Hill, NC: Horizon Research, Inc.

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research (J-PEER)*, *1*(2), 2.

Williams, J. (2011). STEM education: Proceed with caution. *Design and Technology Education: An International Journal*, *16*(1).

ISSN:2149-8504 (online)

APPENDIX A
Teacher Vignette

Thematic Integration – Laura

Laura defined STEM Education as "...trying to combine science, technology engineering and math skills and concepts… and [students] learn how they are associated together and that they are introduced in a hands-on experience instead of just a teacher lecturing about the concepts." Laura continued to comment about how she believed engineering was "how things come together" and she described science as something that "just happens."

Laura described her goals for students when teaching a STEM lesson as primarily a way of keeping her students busy. She explained that she tries to keep her students "doing" all day. Laura describes another general goal for her classroom is trying to include technology because students do all of their tests with technology when they get to high school. Laura speaks about instructional technology use as something she and her grade level teacher colleagues try to incorporate more of, particularly iPads. She also commented that "...it [STEM] is something that was put on the backburner for reading and math…"

The biggest benefit Laura described for having students learn about STEM, was getting students to see how subjects went together. For example, Laura says "I think it is important that kids see how they [subjects], how those pieces are intertwined together. That we have to have an understanding of all of those to do any of those things well." She also felt STEM would help her students to feel okay about making mistakes and to explain their thinking.

Laura submitted a lesson called "Pumpkins Galore" which she created herself that she was not required to teach. The objective of the lesson was for students "...to expose students to the different parts of a pumpkin, practice counting, and to explore different ways to use a pumpkin for fun". Throughout the two-session lesson, students use pumpkins in a variety of activities to make predictions. Students record predictions and noticings on height, weight, color, buoyancy, etc. Students then guess and count the number of seeds in the pumpkin. An art extension is included as an option where students are able to paint or carve their pumpkin. Neither formative nor summative assessments are included in the lesson plan. Additionally, standards being addressed were not included in this lesson plan. The lesson Laura submitted was classified as Thematic Integration as her lesson was focused on pumpkins and all activities revolved around the theme. Davison, Miller, and Methany (1995) described thematic integration as a way of integrating many subjects around a central topic or theme. Laura shared that she tried to structure her STEM lessons in a way that went along with whatever theme or time of the year was taking place, such as the pumpkin lesson because it was around Halloween. When asked how she came up with the idea for the lesson, Laura said that she always carves pumpkins with her class and that she thought this lesson would go beyond "play." Laura continued to describe how her STEM lessons were rarely ever planned out and that she just tries to connect ideas back to science or math as they come up. She shared her frustration with teaching science and that she has no curriculum or materials to use aside from a weekly reader she gets from a school book publishing company. She explains "I don't feel like I am equipped well enough to put all of those pieces together regularly...in our building it [teaching science] is pretty much whatever the teacher chooses to teach and when they teach and how they teach it." Laura shared that because she doesn't have materials provided by her district, she relies heavily on Teachers Pay Teachers and other internet sites to find STEM lessons and ideas. Laura shared that her STEM lessons generally have an art or craft project included because that is what she likes.Laura stated that she had a little bit of professional development in science but none specifically in STEM Education. She shared that she desires professional development on integration and how to make iSTEM Education lesson plans. Laura lamented that while she desires to know more about STEM Education, her building doesn't focus much on STEM as it has taken a "backseat" to reading and math.

No Integration-Mary

Mary defined STEM Education as "... learning how to explore and build on things… create new things…taking a look at how things work… discovering things to learn concepts...a hands-on exploratory approach to learning…trying to solve a problem that has more than one answer…" Mary continued to describe how she felt engineering was a "creation process" and that it was different from science because science is the "core concepts" while engineering is taking those concepts and "creating something to solve a problem."

Mary's biggest goal for students when teaching iSTEM Education was to get students to be independent and to be okay with making mistakes. She described problem- solving as the biggest benefit she sees in teaching iSTEM Education. She stated, "I think it is important to teach them [students] that this is how you're going to have to figure something out because there isn't always going to be an answer."

Mary submitted a lesson plan called "Properties of Matter" which she borrowed from a colleague who got it from Teachers Pay Teachers. The objective for students stated, "Students will describe and sort objects based on color, shape, size, and texture." This lesson was structured as individual thirty-minute lessons that would span for six days. Activities included a nature walk, button sort, class discussion on matter, cracker sort, and the construction of a "Nature Friend" (a craft project using items found in nature to build a "friend" using a Styrofoam cup as the body).

The lesson Mary submitted was classified by the researcher as No Integration. The topic of Mary's lesson is properties of matter, and all activities in the lesson are focused on the subject of science. Students participate in a variety of seemingly disconnected activities, and the final product of the lesson is a "Nature Friend" that is created out of a Styrofoam cup and items students found during a nature walk at the beginning of the lesson. When Mary was asked about integrating STEM subjects in the interview, she stated "...I don't want to say we have dropped out math…we talk about math within our STEM lessons but… I wouldn't say it is 100%…they all kind of work together…not all of our lessons include all four of those things…"

Mary described the way she typically structures her STEM lessons as lasting about thirty minutes every afternoon for science and her lessons focused on students explaining and exploring. She continued that students typically are working together and "...have some sort of hands-on materials that they are manipulating and working with to create some sort of solution…"

Mary shared that she feels she has a wonderful support system when it comes to teaching STEM Education and specifically cited her grade level partner and other teachers in her building. She also mentioned that her building has different resources available for STEM Education as they have a membership to the National Science Teachers Association as well as a grant from the Missouri Partnership for Education Renewal (MPER). However, she commented that she does a lot of internet research and frequently uses Pinterest to find STEM lessons. Mary shared that while she would like to have professional development on teaching iSTEM Education, she was unsure as to how willing many of the other teachers in her building would be to try something new.

Content Specific Integration- Cassie

Cassie defined STEM Education as "…trying to integrate science into as many things as possible… so maybe reading, writing, science all in one... the technology piece like iPads and maybe research...using as much of the iPads and devices…" Cassie continued to admit that she had no idea what the "T" in STEM meant and that she "didn't have a clue" as to what engineering would look like at the elementary level, but she thinks it would have something to do with designing and building.

Cassie's main goal for teaching iSTEM Education is influenced by her school's focus on integrating the expressive arts. She explains "…we are the arts integration school, so everything we do we try to hit as many areas as possible using art, music, drama, dance, even technology... our fine arts objectives or our learning objectives are the main things…" Cassie describes her view on the benefits of students learning about STEM as a way to promote higher-level thinking. She states "…it [STEM] is requiring them to think not just at the base level of input knowledge and just recall...it is all at the higher level of thinking. It really digs in and makes them really think." Cassie also commented on how she believes that STEM Education can aid in encouraging students to have better behavior and be more productive.

Cassie submitted a lesson called "Lunes and Leaf Rubbings" which she got from a colleague who left their school many years ago. She was not aware of the original source, and she was not required to teach it. The objective of the lesson was "Students will experiment with writing lune poems (a form of Haiku poetry) based upon items found in nature." The lesson spanned three sessions and connections to state standards included fine arts and communication arts standards.

The lesson Cassie submitted was classified as Content Specific Integration. Content Specific Integration is when a lesson includes one objective from one subject and one objective from another. Davison, Miller, and Methany (1995) describe Content Specific Integration as using one objective from both math and science. However, in this study, a lesson could be categorized as Content Specific Integration if there were one objective from any two subjects included. In Cassie's case, her lesson included an objective from writing and another from art. When asked to describe her reasons for integrating the arts into her lesson, she stated "...we are the arts integration school so everything we do we try to hit as many areas as possible using art, music, drama, dance, even technology... we really kind of look at it like a big umbrella…" Additionally, Cassie described the difficulty she and others in her school experience when trying to integrate math into their art-focused curriculum because "math is so hard to integrate." Cassie emphasized that at her school science, technology and engineering are not a focus. She clarified that they do teach science but that it is not a focus for them.

Cassie described her typical lesson structure when teaching an iSTEM Education lesson as one that uses guided practice and "would definitely include a movement activity." Her lessons last about an hour and her job would be to model her expectations, so students knew what she expected of them. In the lesson Cassie submitted, she described how movement was integrated into her STEM lesson when her students go outside to observe leaves. She continues "…they get to basically imitate the leaves with their body. So they dance around, they float around, and they twirl. So they are basically observing the leaves and then doing things with their bodies to imitate that …" Cassie also describes how she allows her students who are shy to use finger puppets to help them explain their thinking to their peers.

Cassie commented on how she feels she has a good amount of support for integrating and feels certain that if she went seeking for more STEM support that she would be able to get it. She cited her building art team (specialist teachers in art, music, drama, and dance) as the main source for helping her with integration, as well as the other teachers in her building. She described how helpful her district's science and math coordinators are and that she felt if she asked them for assistance then they would be very good about providing it.

ISSN:2149-8504 (online)

Her instructional resources for STEM are basically their buildings access to Science A-Z and the math and science curriculum provided by her district. When it comes to her resources that aid in her integration strategies, she explained "...I use Pinterest...we use Pinterest a lot to find ways that we can integrate as much as possible…"

Cassie shared that she was a bit apprehensive about how her building would react to any iSTEM Education professional development because it just wasn't a focus for them. She explains "...I'm not knocking STEM, but…again I think it is important so obviously, we have a need for pd, but…it is not something I feel like our building would focus on." Cassie stressed that perhaps individual teachers might go out and find STEM professional development and she might be interested to see what it would look like at the elementary level, but she really felt that she and the teachers at her building are solely focused on what they are doing at their building, which is focusing on the arts.

ISSN:2149-8504 (online)

Methodological Integration- Sidney

Sidney defined STEM Education as "... taking science to a new more modern day level... the future careers and the future of our country and world is more based in science, technology, engineering, and mathematics…". She continues "…our kids are sadly too much in just rote memorization of basic scientific facts. So it is becoming more hands-on and real world applicable for solving problems within those fields." Sidney also described engineering as a building and design process and cited multiple careers where engineering design processes are used.

Sidney has many learning goals for her students when teaching a STEM lesson, but she comments on how her primary goals come from her state standards. She discusses the responsibility of public school teachers to stick close to their state standards. Her secondary goal, which she hits on multiple times throughout her phone interview, is focused on student retention. Sidney also has an overarching goal of getting students to be well-rounded and proficient at many different things. She sees this as both a goal and a benefit for having students learn STEM Education. Sidney focuses on the future needs of her students and how they will need to be "well-versed in multiple areas" to be good at most jobs. She describes the need for students to be problem solvers and to realize that students need to be able to create and implement their own ways to come up with a solution.

Sidney submitted a lesson plan called "Problem Solvers" which she adapted from a book called Even More Picture Perfect Science by Ansberry and Morgan (2010). Sidney was not required to teach this lesson. There were six different learning outcomes included in this lesson and five science and math Missouri Learning Standards. This lesson was structured as a 5E lesson that would span over five separate class periods, each lasting thirty to ninety minutes each day. A student assessment and modifications or accommodations were also included.

The lesson Sidney submitted was classified as Methodological Integration. Davison, Miller, and Methany (1995) essentially describe Methodological Integration as a method of integration that investigates issues, for example, in science and math using discovery, inquiry, and the learning cycle. There is a building of knowledge that occurs within the lesson as students progress. Sidney's lesson uses the 5E Learning Cycle (Engage, Explore, Explain, Extend, and Evaluate) and students are working to solve problems.
Sidney explained that her STEM lessons don't follow a typical structure, but she does have about two to three hours a week for teaching her "old-school" science lessons. Sidney utilizes Genius Hour and Makerspaces in both her classroom and her after-school club, while also using instant challenge task cards from Discovery Innovation. Sidney says her lesson structure depends on the activity. For example "...I do Makerspace in my classroom twice a week for about an hour each time…we started with task cards that are open ended… like create a robot…there is like 100 task cards that I got from our gifted teacher…" Sidney commented that she is trying to provide more opportunities for her students to engage in exploration and becoming a more student-centered educator.

Sidney stated that she didn't really feel like her district is providing her with any materials or resources to assist her with her STEM teaching as they aren't quite on board with STEM Education yet. Sidney remarked that her main source of STEM support comes from other teachers in her building, such as her grade level partners and the gifted teacher. Sidney described that she has taken the responsibility to write grants for money needed to purchase STEM materials and that she uses various internet resources such as Google and YouTube for lessons and ideas. When asked about the areas she desired more professional development, Sidney had a lot to say. She explained that she would like more professional development in developing lessons and how to find resources that are free or affordable. She discussed her understanding of the importance of STEM Education but said she just doesn't know how to get it done by herself.

ISSN:2149-8504 (online)

Process Specific Integration- Kim

Kim defined STEM Education as "... Science, Technology, Engineering and Math education...I am lucky enough to teach in an arts integrated school so STEM would be more science, technology, engineering, art, and math integrated...so pulling those subjects into all parts of teaching." Kim explained the difference between engineering and science as engineering being "the study of how things are built and how things are made and created." She explained that she felt engineering was an aspect of science but was more "process related."

Kim's goals for students when teaching STEM begins with the objective for the lesson and the content being taught. She explained that if she was teaching a social studies lesson, then her primary objective would be that students had correct social studies content information. She stated that if say, technology was the focus of the lesson and the content was secondary, then she would be looking for mastery of the technology skill. Kim shared she felt STEM Education was beneficial for students because it helped them to be "well-rounded." She commented on how technology is changing "minute by minute" and how students need to be able to change with it. She also felt problem-solving, and collaboration skills were important benefits of students participating in STEM Education. Kim also commented on how she believes some students are more successful in STEM Education than others. As an example, she cited a student in her class who is "gifted" and "math minded" but is not necessarily creative. She says "…he is creative, but he is not a visual artist. He is not a great singer, he is not a great actor, but he is great with math and numbers and really good at problem-solving…so that helps."

Kim submitted a lesson plan called "Towering Towers" which she got from a colleague "many years ago." Kim was unsure of where the lesson originated, but she was not required to teach it. The goal of the lesson stated "As a team, you must only use the given materials, to build a tower that will support a ping-pong ball. Points are given for originality, neatness, height, and cost of materials". This lesson would take place during a single class session. There were no standards or objectives included in the lesson.

Kim's lesson was classified as Process Specific Integration. Davison, Miller, and Methany (1995) describe Process Specific Integration as an approach where students use real life activities to engage in science and math processes. Solving a problem is a part of process integration and Kim's lesson, while not exactly a real life problem, poses a problem for students to solve as a team. Students are expected to build a tower using only the materials provided and considering the cost of all materials used.

Kim explained the structure of her STEM lessons when she stated: "...depending on the lesson it is either, you know I will introduce the objective and then do a gradual release of content". She continued her description by saying she tends to incorporate a lot of technology into her teaching. She likes to use Schoology as a platform for paperless work and uses Google Apps, QR Codes, and other apps in her classroom as her students are all 1:1 with iPads. When asked how she integrates science, technology, engineering and math, Kim stated that she hadn't taught science in about ten years as her school departmentalizes. She commented she tries to integrate math but "Math is one of the hardest subjects to use art integration." She also commented on how she utilized other teachers, district coordinators, and the internet for help when developing her STEM lessons. Kim desired professional development in integration, specifically with the arts as she is at an arts school. She wants to be able to integrate STEM with the arts but would like it not to be "a chore or something extra...just make it kind of natural."

ISSN:2149-8504 (online)

Journal of Research in STEM Education

Vol 4, No 2, December 2018, 179-192

RESEARCH REPORT

Factors Influencing Student STEM Career Choices: Gender Differences

Tandra Tyler-Wood[a1], Karen Johnson[a], Deborah Cockerham[b]

[a]University of North Texas, USA; [b]Fort Worth Museum of Science and History, USA

Abstract: *This study examined factors that influence middle school students' dispositions towards science, technology, engineering, and math (STEM) careers. Interest and ability in STEM subject areas were compared by gender, based on 182 middle school students' responses to four different test instruments. While findings from t-tests indicated significant differences between males and females on mathematics interest scores, no significant differences were found in science, technology, engineering, or STEM career interest. Stepwise multiple regression showed that STEM variables explained 47% of the variance in boys pursuing a STEM career and 36% of the variance in girls. The findings of this study underscore the challenges that still exist in achieving equal gender representation in the STEM workforce, and suggest that adopting a constructivist learning approach may provide a foundation for girls to develop a more positive approach toward science, boost STEM awareness and interest, and increase STEM success.*

Keywords: Constructivism, STEM education, STEM careers, gender gap

Introduction

The fields of science, technology, engineering, and mathematics (STEM) are critical to national and global competitiveness in the technologically-driven economy. These disciplines have been designated as high priority educational areas by the National Education Agency and other federal agencies (Goan & Cunningham, 2006). Increased need for STEM professionals is driven by factors such as real and immediate economic and societal needs (Connors-Kellgren, Parker, Blustein, & Barnett, 2016): retirement of baby boomers, projected STEM job opportunities (Mau, Perkins, & Mau, 2016), national and strategic significance, the need for a homegrown STEM workforce, and the equity and value of a diverse workforce (Connors-Kellgren, et al., 2016). Work in the STEM fields drives innovation and has an immense impact on competitiveness, economic growth, and the overall standard of living (U.S. Economics and Statistics Administration, 2017).

In response to the need for a qualified workforce, the U.S. has invested in STEM education (Wang & Degol, 2013) through agencies such as the U.S. Department of Education and the National Science Foundation (NSF), which both support extensive research and education in STEM programs (ConnorsKellgren et al., 2016). Policy maker and employer investment in STEM education has often been motivated by evidence of the macroeconomic benefits of preparing students for STEM careers (Connors-Kellgren et al., 2016).

Over the past ten years, employment has increased much faster in STEM occupations (24.4%) than in non-STEM occupations (4.0%). Opportunities in the STEM professions are projected to grow by 8.9% between 2014 and 2024. In 2015, 9 million STEM workers were employed in the U.S. (U.S. Economics and Statistics

[1] Corresponding author. UNT Departmant of Learning Technologies, Discovery Park, G155 E-mail: tandra.wood@unt.edu

Tyler-Wood, T., Johnson, K., & Cockerhan, D. (2018). Factors Influencing Student STEM Career Choices: Gender Differences. *Journal of Research in STEM Education*, *4*(2), 179-192.

ISSN:2149-8504 (online)

Administration, 2017). However, the need to meet the demands of the labor market has spurred significant concerns about a future deficit of STEM workers (Jackson, Charleston, Lewis, Gilbert, & Parrish, 2017; US Bureau of Labor Statistics, 2015; Wang & Degol, 2013).

While recent research indicates that the numbers of STEM graduates are increasing (Salzman, 2013), male students continue to strongly outnumber females in some STEM fields of study (Jackson, et al., 2017; Kanny, Sax, & Riggers-Piehl, 2014). Although recent research suggests a narrowing of gender differences in fields such as biology (Kanny et al., 2014), females are generally underrepresented in STEM programs, especially in engineering, computer science (Kanny et al., 2014; Sax, 2012; Jacobs, 1996), and math (Salzman, 2013; Wang & Degol, 2017). Furthermore, the National Center for Education Statistics (Aud et al., 2012) indicates that the percentage of women receiving bachelor's degrees in engineering has increased only slightly (14% to 17%) over the past 25 years, and the number of women receiving bachelor's degrees in computer science has significantly declined (36% to 18%).

Current studies suggest paradoxical findings: although STEM professionals are predominantly male, girls generally achieve higher grades in mathematics than boys. Higher grades indicate ability for success in mathematics studies, a strong precursor of success in STEM careers. (Stoeger, Duan, Schirner, Greindl, & Ziegler, 2013; Wang, Degol, & Fe, 2015). Despite the vast body of research that attempts to explain both the gender gap in STEM programs and the continued deficit of females in STEM course enrollment, female involvement in certain STEM fields has remained consistent (Wang & Degol, 2013). Because the reasons for the gap may have changed through the years (Kanny, et al., 2014), an understanding of factors that influence girls' educational and career choices and motivations that may encourage female interest in STEM careers is critical. Academic and affective predictors for STEM career choices as early as elementary and middle school education must be examined (Kanny et al., 2014).

The purpose of this study is to investigate factors that may influence middle school students' career preferences. The primary question is: Are 7th grade male and female student attitudes towards a STEM career influenced by similar factors? Student spatial skills, ability and performance levels, and interest in STEM subjects will be examined.

Theoretical Framework

Human constructivist learning is used in this study as a theoretical lens to explain factors that influence middle school students' attitudes, interests, and performance in STEM education and STEM career choices. Human constructivist learning offers a philosophical view about how humans learn (Ultanir, 2012) and significantly influences the modern education system. Success in the twenty-first century requires teaching strategies that allow students to make meaning and build knowledge (Mintzes, Wandersee, & Novak, 2005). Constructivist theory emphasizes the meaning-making capacity of the human mind and is based on an understanding of how knowledge is constructed and how humans learn (Mintzes et al; Ultanir, 2012). Constructivism focuses on the recognition that learning requires active cognitive engagement (Bretz, 2001), and focuses on active, student-directed learning (Yager, 1991, p. 53). In this model, learning is not dependent upon teacher presentations, but takes place as the student assimilates new information into his previous knowledge and perceived notions (Yager, 1991).

In the past, the behaviorist approach to teaching and learning dominated U.S. pedagogy (Yager, 1991), but this approach does not support deep understanding or development of skills required for synthesis and transfer (Yager, 1991). Deep understanding is constructed from learner experience, knowledge, ideas, and activities (Ultanir, 2012), and is supported as students learn words, sentences, and stories to make sense of the environment and communicate concepts (Yager, 1991).

The teacher who utilizes a constructivist approach serves as a guide, encouraging the learner to question, challenge, and formulate his own ideas, opinions, and conclusions (Ultanir, 2012). Learning is extended beyond the classroom so that students view science as more than something that merely exists to be mastered on tests

ISSN:2149-8504 (online)

(Yager, 1991). Adopting the constructivist approach to teaching may help to reduce the gender gap in STEM education. A constructivist approach may provide a foundation upon which females develop a more positive approach toward science, boost STEM awareness and interest, and increase STEM success.

Literature Review

Women's underrepresentation in STEM careers has been rigorously researched over the past 25 years (Kanny et al., 2014). While some studies (Cheryan, et al., 2017) suggest that gender differences in STEM interest usually appear before college, others (Freeman, 2004, cited in Tyler-Wood, Ellison, Lim, & Periathiruvadi, 2011) suggest that STEM achievement does not show significant gender differences. In order to capture major factors influencing the gender disparity, our studybegan with a review of two meta-analyses. Blickenstaff (2005) analyzed literature on the gender gap from 1970 through 1991, and proposed nine contributing factors of women's underrepresentation in STEM: 1) biological differences, 2) academic preparation, 3) attitude toward STEM, 4) a lack of role models, 5) curriculum, 6) pedagogy, 7) "chilly" climate in STEM classes, 8) gender-role socialization, and 9) epistemological differences. More recently, Kanny et al. (2014) investigated research addressing the evolvement of scholarship on the STEM gender gap over four decades (1970 to 2010). This study is inclusive of more current studies and represents a value-added follow up to Blickenstaff's (2005) research. Based on a systematic review of 324 peer-reviewed texts, the study identified patterns and themes in five dominant narrative explanations: 1) individual background characteristics, 2) structural barriers in K-12 education, 3) psychological factors, values, and preferences, 4) family influences and expectations, and 5) perceptions of STEM fields. Some of these phenomena affect children as early as age 4 and continue to affect attitudes, interests, perceptions of, and experiences in STEM throughout K-12 education. Despite evidence that many efforts have been made to address the gender gap, the discrepancy persists (Wang & Degol, 2013). Reasons for the gap may have changed, but these remain unclear (Kanny et al., 2014).

Women in STEM Careers

Some STEM fields are relatively gender-balanced, while others are largely ignored by women. For example, women receive more than half of the U.S. undergraduate degrees in biology, chemistry, and mathematics, but less than 20% of computer science, engineering, and physics undergraduate degrees (National Science Foundation, 2014). Although years of extensive research on the gender gap issue has been conducted in a wide cross section of disciplines, the extant literature is limited (Wang, Degol, & Ye, 2015). Many of these studies view the college major as the primary determinant for outcome and STEM performance and career choice (Lubinski & Benbow, 2006), but multiple factors have already come into play by the time a student is in college (Tyson, 2011). Other efforts focus on increasing student exposure and performance in high school math courses (Eccles, 2009), but evidence that career aspirations are formulated in the earlier years suggests that investigations should begin in the first educational encounters.

Signs of the gender gap surface as early as elementary school, with males and females exhibiting comparable STEM performance, but less interest in STEM among girls than boys (Unfried, Faber, & Wiebe, 2014). Currently, most literature still seeks to understand ways to increase the number of women who pursue and persist in STEM (Cheryan, Ziegler, Montoya, & Jiang, 2017), but little evidence to date indicates specific factors that explain women's underrepresentation in some STEM fields (Cheryan et al., 2016). In order to unearth some of the contributing reasons for the gap from an early age, our research focused on seventh grade students' dispositions towards STEM careers. More specifically, we examined boys' and girls' interests in STEM and/or STEM careers as well as STEM-related subject/content areas required to develop skill sets needed to pursue STEM education. The content areas investigated are spatial reasoning skills and visual perception (Shapes Test), general thinking processes in science and mathematics (Trends in International Mathematics and Science), and scientific understanding involved in construction of a solenoid.

Attitude and Preference Toward STEM

Attitude and preference may play large roles in gender disparity for STEM interest and career choice. A 1995 meta-analysis of studies conducted between 1970 and 1991 (Weinburgh, 1995) suggested that males' attitudes towards science are generally more positive than are females' attitudes, and that attitude towards science underscores STEM achievement. An observational study of interactions at a children's science museum found that parents tend to spend more time explaining scientific exhibits to boys than to girls (Crowley, Callanan, Tenenbaum, & Allen, 2001). With this parental guidance, boys will more naturally develop a positive inclination for STEM. Similar experiences have likely influenced gender gaps in college students' goals (Dabney & Tai, 2014).

A meta-analysis of 47 career interest inventories, looking at scores of over 500,000 participants (Su, Rounds, & Armstrong, 2009) suggested that career preference may vary markedly by gender. Results indicated that, in general, men prefer working with things, while women prefer working with people. However, authors cautioned that the wording of questions on specific inventories may skew the results, and advised vocational counselors to consider this fact in selecting instrumentation. An action research study (Tyler-Wood, Ellison, Lim, & Periathiruvadi, 2011) explored the development of positive attitudes among females. In this study, 34 fourth and fifth grade girls were paired with female high school science mentors, and engaged in outdoor, "hands-on" science experiences. Results showed that most of the participants increased in scientific awareness and confidence. Therefore, adopting a constructivist approach could increase the likelihood of attitude and preference toward STEM across genders.

Gender Differences in STEM Ability, Performance, and Career Interest

Multiple studies investigating gender differences in math performance suggest comparable math ability, but slightly stronger female performance (Lindberg, Hyde, Petersen, & Linn, 2010; Voyer & Voyer, 2014, cited in Diekman, Steinberg, Brown, Belander, & Clark, 2017). A 2007 study examining subskills involved in both math and science found that, while females are generally more proficient in writing and other essential STEM communication skills, males have a stronger understanding of abstract ideas (Halpern et al., 2007). Authors attributed these gender differences to a combination of early experience, biological factors, educational policy, and cultural context, and found similar ability results for both males and females.

Since ability levels appear to be similar for boys and girls, Diekman et al. (2017) suggest a communal goal congruity model to motivate students to choose STEM careers. This model explores the impact of community goals upon decisions to pursue STEM careers, with communal goals defined as those that provide the opportunity to be with or to help others. Girls often gravitate more towards the communal expectations, which are not traditionally perceived as STEM careers. Perceptions of expected social roles appear to begin in early childhood, and are important components of self-perception and motivation (Cross & Madsen, 1997). If girls are made aware of the importance of socially oriented STEM jobs through human constructivist learning, their interest in STEM careers may extend into areas that are currently underrepresented by females.

Gender Differences in Spatial Ability

Studies involving spatial ability (Jeng & Chen, 2013; Hedman et al., 2006, Ceci & Williams, 2007) show the importance of spatial subskills for learning STEM concepts. Spatial ability is multi-faceted, and individual studies have shown discrepancies in identifying and labeling its various components. While Stumpf and Eliot (1995) identified subskills such as mental rotation, visual memory, and a strong "general factor", a meta-analysis of 172 empirical studies (Linn & Peterson, 1985) defined key factors as spatial perception, spatial visualization, and mental rotation.

In spatial perception tests, each participant must examine spatial relationships between the object or picture and the orientation of his own body. Spatial visualization describes the ability to mentally rotate whole or partial 3D objects in space. In a study that investigated the involvement of spatial visualization and logical reasoning skills in high school geometry achievement, Battista (1990) found that males were significantly stronger than females in spatial visualization. Whereas males tended to use spatial visualization for problem solving, females used verbal skills and logical reasoning. Problem solving scores between genders were comparable.

Mental rotation, which involves the ability to mentally rotate 2D or 3D objects (Linn & Peterson, 1985) has been implicated as a key factor in gender differences. In a study that investigated elementary students' developmental and gender differences, Jeng & Liu (2013) found interesting variations. Performance on mental rotation tasks was stronger for fourth and fifth grade females than for age-matched males. However, by sixth grade, the gender gap had grown, and male performance had moved beyond that of females. Authors, noting that fifth grade (around age 10) appeared to be a critical time for building spatial skills, attributed this change to the more abstract and application-based instructional approach to sixth grade spatial concepts. They asserted that "mental rotation" tasks became "spatial visualization" tasks in sixth grade, and concluded that more direct instruction in concept application could narrow the gender gap. A study by Stumpf and Eliot (1994) further revealed this trend, with middle and high school males outperforming females on mental rotation, but females excelling in visual memory tasks.

The purpose of the current study is to investigate factors that influence middle school students' career choices. More specifically, the study aims to investigate the spatial skills, ability and performance levels, and interest of middle school students in subject areas that will create a direct pathway to STEM programs and ultimately STEM careers. The overarching research question guiding this study is:

Are 7th grade male and female student dispositions towards a STEM career influenced by similar factors?

Sub-questions to be investigated are:

1. Do 7th grade male and female test scores differ in variables related to STEM?
2. Do these factors predict a best fit model for 7th grade male and female attitudes towards a career in STEM?

Test scores will help to determine boys' and girls' attitudes and abilities toward STEM in each of the following areas:

1. Science, technology, engineering, math, and/or STEM career (STEM Semantic Survey)
2. Knowledge of STEM (TIMSS)
3. Visual perception (SHAPES test)
4. Knowledge of solenoid (Solenoid Test)

This study aims to broaden the understanding of factors influencing STEM career choices and to guide future gender gap STEM research.

Research Method

Since factors that influence gender decision toward STEM education and career are still being investigated, an exploratory research approach was utilized for this study. While exploratory research does not offer conclusive evidence for the existing problem, this approachexplores the problem with varying levels of depth, leading to new insights and better understanding (Singh, 2007). Although causal factors influencing the gap have been suggested, questions concerning the reasons for female underrepresentation in STEM still abound.

ISSN:2149-8504 (online)

Research Context and Samples

Seventh graders (N = 182) in two Title I rural Texas school districts participated in this study, which was part of a large NSF project (NSF1510289). The two school districts were chosen based on access and their similarities in demographics. Only pre-intervention data that were gathered prior to the initiation of the sponsored study were assessed; no post intervention data from the sponsored study was included in this analysis. The actual number of students completing each assessment varied, since some student surveys were incomplete and other students were absent when specific surveys were given. Table 1 lists number of respondents by survey. Data was not used for students who did not complete a survey or who were absent when a survey was taken. Students with missing data critical to an analysis were removed from the data set for that analysis.

Table 1.
T-test Comparing Means of 7th Grade Girls and Boys on STEM Variables

	Gender	N	Mean	SD	Sig
Science Subtest*	Male	88	13.92	5.38	.22
	Female	87	15.03	6.68	
Technology Subtest*	Male	88	10.13	5.62	.83
	Female	87	10.30	5.10	
Engineering Subtest*	Male	88	12.20	7.50	.26
	Female	87	13.45	7.17	
Mathematics Subtest*	Male	88	17.25	7.80	.05
	Female	87	19.84	9.47	
STEM Career Interests*	Male	88	15.14	6.55	.62
	Female	87	15.35	6.43	
Solenoid	Male	84	3.75	1.77	.17
	Female	86	4.09	1.48	
TIMSS	Male	84	3.96	1.83	.93
	Female	84	3.94	1.50	
Shapes	Male	84	17.99	2.08	.97
	Female	82	18.00	2.25	

*=reversed scale, low numbers equal higher affinity towards subject area.

School I is a middle school that houses around 400 seventh and eighth grade students. Roughly 70% of students are ethnically white, 23% are Hispanic, and 3% are African Americans. The remaining students are Native American, Asian, or biracial. This campus has an economically disadvantaged population of 45%. School 2 is a middle school with a population of 220 students in grades seven and eight. The ethnic distribution of this campus includes 61% white, 31% Hispanic, 2% African American, and 6% Native American, Asian, or biracial. The population of economically disadvantaged students at School 2 is 64% of the total. Student surveys were administered by the school technology directors, and were completed online through Survey Monkey.

Instrumentation

During the spring of the 2016-2017 academic year, students in both schools were tested with the following instruments: STEM Semantic Survey (subtests: affinity towards science, technology, engineering, mathematics, and career in STEM), Trends in International Mathematics and Science Study (TIMSS) Limited

ISSN:2149-8504 (online)

Administration, Shapes Test, and Understanding a Solenoid. Demographic data were also collected.

STEM Semantics Survey. The STEM Semantics Survey (Tyler-Wood, Knezek, & Christensen, 2010) was used to measure students' interest in science, technology, engineering and mathematics as well as interest in STEM careers. The survey is comprised of five scales, each with five items measured on a 7-point scale. The scores that are obtained when the instrument is scored are an inverted scale where a score of one indicates a very high affinity toward the STEM item and a seven indicates a very poor affinity towards the item. In the original study (Tyler-Wood, Knezek, & Christensen, 2010), reliability estimates ranged from 0.84 to 0.93, which are considered to be "very good" to "excellent" (DeVellis & Dancer, 1991) (See Appendix 1). Internal consistency ratings for the five subscales from this data set ranged from 0.82 to 0.84, with an overall rating of "very good" (DeVellis & Dancer, 1991). The instrument lists adequate content and construct validity (Tyler-Wood, Knezek, and Christensen, 2010).

TIMSS Limited Assessment. The TIMSS assessment used in the current study (Stansell & Tyler-Wood, 2016) represents a locally developed academic test comprised of items adapted from the previously released Trends in International Mathematics and Science Study (TIMSS) questions. TIMSS math and science questions were selected based on specific content related to general thinking processes in science and math that are not content specific (Stansell & Tyler-Wood, 2015). Schult and Sparfeldt (2016) established the concurrent validity of the TIMSS multiple choice items by comparing the math and science grades of students to their scores on the TIMSS (r=.5). This correlation indicates that the TIMSS multiple choice items have a moderate predictive value for grades. Reliability was established by comparing multiple choice and constructed response items (r=.94). The reported reliability of the TIMSS is high.

Shapes test. The Shapes Test (Tyler-Wood, 2015) was developed as a quick assessment for spatial reasoning skills. The Shapes Test consists of 20 questions that were produced in a grid format with the stimulus image in the far left box and the selection items to the right as shown in the sample item below (see Figure 1). While the demonstration items were presented on a reusable laminated document, the 20 test items were presented to the students on paper so that they could circle their choices.

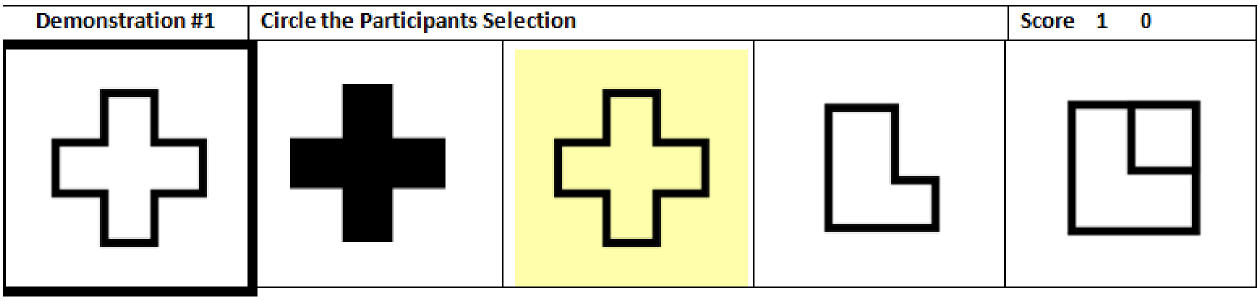

Figure 1. *Shapes Test sample item. The participant marks the best match (highlighted in this example) for the first item in the row.*

Zimmerman (2016) provides evidence of validity and reliability for the Shapes Test, and has compared the Shapes Test to the Cube Design section of the Universal Non-verbal Intelligence Test. A bivariate Pearson Correlation was performed to determine if the two variables were related to each other. The Pearson's coefficient obtained was .349, indicating a moderately strong correlation. Zimmerman performed a test-retest analysis to establish reliability and obtained a Pearson Correlation of .465 (moderately high).

Understanding a solenoid. The solenoid test contains six items, each scored with a Likert scale rating of 1 to 3. This assessment was developed with NSF funding and measures students' understanding of a solenoid. The test consists of multiple choice items with corresponding descriptive responses. Previous uses of the test

ISSN:2149-8504 (online)

have indicated that increases in test scores occur as a result of participating in the solenoid instructional unit (Rutter, Standish, & Bull, 2016). For analysis of the assessment, a panel of experts developed a scoring rubric of descriptive responses. Content related validity was established through consensus agreement of a math professor, a science professor, a math teacher, and a doctoral student studying Curriculum and Instruction with a bachelors in engineering. Each member of the panel coded the results individually, and they convened as a group to discuss their decisions. Consensus was reached between all members on most questions, and notes of explanation were included for the few questions without consensus. Inter-rater reliability is reported at above .90.

Procedures

Data were analyzed from an existing, large NSF data set to identify differences between 7th grade boys and girls regarding their attitudes and abilities in STEM. Independent t-tests were run on each of the following dependent variables: STEM Semantic Survey, TIMSS limited assessment, the Shapes Test, and Understanding a Solenoid. Gender (male, female classification) served as the independent variable. An overall stepwise multiple regression was run to determine the best model for predicting 7th grade boys' and girls' interest in a STEM career. Stepwise regression is a tool that helps to identify useful predictors during the exploratory stages of model building for linear regression. It constructs a single model using the p-values of the predictor variables, and the key benefit is the simplicity of the single model. As the current study is exploring how STEM variables relate to career preference, stepwise regression was selected to evaluate whether students' affinities towards and knowledge of STEM-related subject areas (dependent variables) are necessary to predict gender (independent variable) interest in STEM careers. The analyses were conducted using SPSS version 24.0.

Results

The results of the study will be reported in two parts. First, results from t-tests will be noted to describe statistical significance between independent and dependent variables. Second, the results from stepwise multiple regression analysis will be discussed in relation to the research questions.

T-test Analysis

T-tests addressed the first research sub-question: Do 7th grade male and female scores differ in variables related to STEM? T-tests completed on the subtests of the STEM Semantic Survey indicated no significant differences between boys' and girls' scores on the following Science, Technology, Engineering, and Career Interest subtests (see Table 1):

- Science subtest: boys ($M=13.92$, $SD=5.38$); girls ($M=15.03$, $SD=6.68$; $t\,(-1.22)=173$, $p = .22$)
- Technology subtest: boys ($M=10.13$, $SD=5.65$); girls ($M=10.30$, $SD=5.095$); $t\,(-.21)=173$, $p = .83$)
- Engineering subtest: boys ($M=12.20$, $SD=7.50$); girls ($M=13.45$, $SD=7.17$); $t\,(-1.12)=173$, $p = .26$)
- Career interest subtest: boys ($M=15.14$, $SD=6.55$); girls ($M=15.35$, $SD=6.43$); $t\,(-.21)=173$, $p = .84$)

However, on the mathematics subtest, a significant difference was seen in the scores for boys ($M=17.25$, $SD=7.80$) when compared to girls ($M=19.84$, $SD=9.47$); $t\,(-1.97)=173$, $p = .05$).

An independent t-test was performed on the tests, with no significant difference seen for the following tests:

- Understanding the Solenoid test: boys ($M=3.75$, $SD=5.38$), girls ($M=4.09$, $SD=1.48$); $t\,(-1.37)=168$, $p = .17$)
- TIMSS test: boys ($M=3.96$, $SD=1.83$), girls ($M=3.94$, $SD=1.50$); $t\,(.092)=166$, $p = .93$)
- Shapes Test: boys ($M=17.99$, $SD=2.08$), girls ($M=18.00$, $SD=2.24$); $t\,(-.04)=164$, $p = .97$)

ISSN:2149-8504 (online)

The above t-tests addressed the first research question: Do 7th grade male and female middle school students' scores differ in variables related to STEM? Overall, except for the mathematics subtest on the STEM Semantics Survey, no difference was found between the scores of boys and girls in relation to STEM.

Stepwise Multiple Regression Analysis

Stepwise multiple regression analyses addressed the first research sub-question: Do these factors predict a best fit model for 7th grade male and female attitudes towards a career in STEM? Stepwise multiple regression was performed to determine the capability of STEM variables for predicting career interest for girls. Three variables surfaced as a "best model" (engineering interest, math interest, and technology interest). A significant regression model was found (F (3, 447.91=13.97, p=.000), with an R2 value of .36. This indicates that interest in engineering, math, and technology explains approximately 36% of the variance in the likelihood that girls would pursue a STEM career.

Stepwise multiple regression was performed to determine the capability of STEM variables for predicting career interest for boys. Four variables surfaced as a "best model" (science interest, engineering interest and mathematics interest, and scores on the understanding of a solenoid). A significant regression model was found (F (4, 400.38=16.42, p=.000), with an R2 of .47. Overall, science, engineering, mathematics interests, and understanding of a solenoid explain 47% of the variance in boys' pursuing a STEM career. The common predictors that were kept in the model for both boys and girls seeking a STEM career are their interests in engineering and math. While the results of this study showed technology as a factor in the model predictor of girls' interest in a STEM career, technology was not a factor in the model for boys pursuing STEM careers. Instead, interest in science and knowledge of a solenoid were factors in the model for boys' interest in a STEM career. Visual perception (shapes test) and TIMSS did not account for any of the variation in predicting either genders' interest in moving on to a STEM career at the middle school level.

Table 2.
Model for Predicting Career Interest for 7th Grade Girls from STEM Related Variables

Model	R	R Square	R Square Change	Sig. F Change
Engineering	.483	.233	.233	.000
Math	.558	.311	.078	.004
Technology	.599	.358	.047	.002

Dependent Variable: Career Interest

Table 3.
Model for Predicting Career Interest for 7th Grade Boys from STEM Related Variables

Model	R	R Square	R Square Change	Sig F Change
Science	.552	.304	.304	.000
Engineering	.621	.386	.082	.002
Math	.662	.439	.053	.010
Solenoid	.686	.470	.031	.040

These two regression analyses respond to research subquestion 2: Do the same factors predict a best fit model for 7th grade male and female students' dispositions towards a career in STEM? Stepwise regression produced a stronger model for predicting boys' interest in a STEM career (R2=.48) versus girls' interest in a

ISSN:2149-8504 (online)

STEM career (R2 =.358). The "best fit model" for predicting career interest varied between boys (science, engineering, mathematics, solenoid knowledge) and girls (engineering, mathematics, and technology interests) (See Tables 2 and 3 and Figure 2).

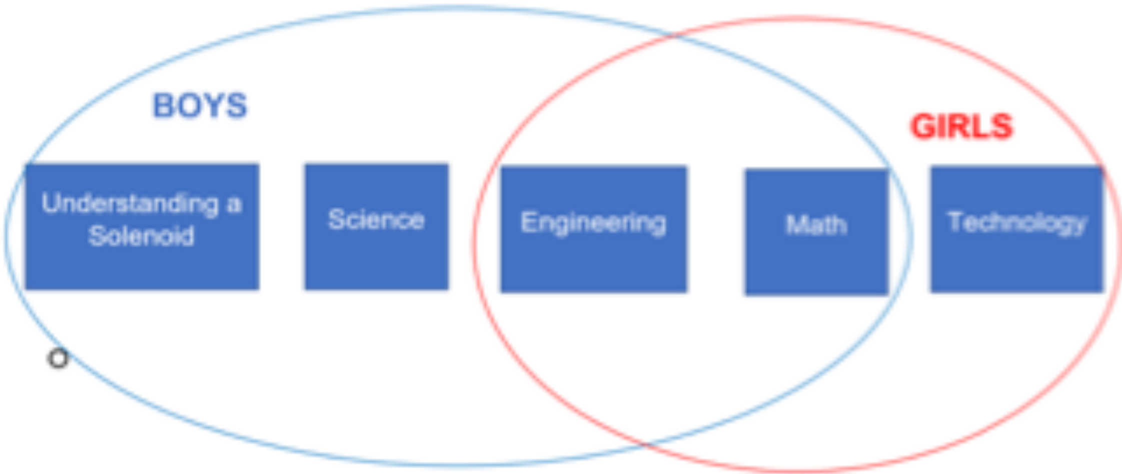

Figure 2. *Interests impacting 7th grade students' preference for STEM careers according to gender*

Discussion and Conclusion

The purpose of this study was to investigate factors that influence middle school students' career preferences, particularly in subject areas that create a direct pathway to STEM education and STEM jobs. Any field that attempts to predict human behavior typically has R-squared values lower than 50%, since humans are harder to predict than physical processes (Frost, 2013). The predictive value of the stepwise regression for boys approached the 0.50 marker, indicating that these variables have a fairly strong potential of predicting interest in a STEM career. The findings from this study confirm existing research by providing additional evidence that, in general, males continue to strongly outnumber females in STEM career interest (Jackson, et al., 2017; Kanny et al., 2014).

Although the R-squared values for predicting a STEM career may appear low, particularly for girls, these are statistically significant predictors. Changes in the predictor values that are associated with changes in the "best fit" models produced through stepwise regression can be valuable in looking at factors that may influence STEM career choices across gender. No significant differences were found between boys' and girls' STEM variable scores except for interest in math. Historically, girls have scored lower and displayed less interest in math (Salzman, 2013; Wang & Degol, 2017). Math interest is a significant predictor of whether girls will pursue a career in STEM. The relationship between math skills, math interest, and interest in a STEM career needs further investigation.

In our study, the ability to understand a solenoid influenced boys' interests in STEM careers more than it influenced girls' interests. Because success often leads to interest, it is likely that boys experienced more success with the abstract, application-based solenoid unit than did the girls. This supports previous findings of lower math performance among boys than girls until around sixth grade, when the instructional approach becomes more abstract and application-based (Jeng & Liu, 2016). If, as these authors theorize, "mental rotation" tasks become "spatial visualization" tasks around this time, perhaps middle school girls' interest in STEM would increase if supported by instructional techniques that encourage deep thinking and learning success.

Results from our study found no significant difference between boys' and girls' test scores in science, technology, or engineering. In addition, there was no difference in gender scores on the career interest subtest.

ISSN:2149-8504 (online)

This supports previous research positing that ability levels appear to be similar for both boys and girls (Diekman et al., 2017), and indicates that both genders are potentially able to pursue STEM education and careers (Stoeger et al., 2013; Wang et al., 2015). Efforts to reduce the gender gap in STEM must extend throughout and beyond the K-16 educational settings, with educators and parents reinforcing the viewpoint that girls can be equally competitive and successful in STEM (Xu, 2016). Placing less emphasis on gender role education will create an environment that will better enable girls to openly express interest in and explore STEM education (Xu, 2016).

Applying the human constructivist learning theory as an explanation of the variation in the relationship strength of boys' and girls' interests, abilities, and performance in STEM appears warranted. Adopting an approach to teaching that is student centered, whereby students have the opportunity to actively engage in the learning process as new knowledge, ideas, and experience are constructed, will allow both boys and girls to better understand their environments (Ultanir, 2012; Yager, 1991). This approach to learning extends beyond the formalities of the classroom (Yager, 1991). Findings from an action research study (Tyler-Wood, et al., 2011) support this approach, as fourth and fifth grade girls increased in scientific awareness and confidence after engaging in outdoor hands-on science experiences.

Limitations. The limited number of participants (182 seventh grade students) and similar socioeconomic status of most students may hinder generalization of results.

Future directions. Future studies should extend the investigation to include students from other elementary and middle school grades. Analyzing specific factors through a variety of data collection methods and research designs could expand and add depth to the understanding of student career preferences. Since current study results explain only 36% and 47% of the variance of boys' and girls' interest in STEM careers, other factors clearly contribute to STEM interests. Additional factors influencing the potential for STEM education and careers should also be investigated among younger students.

The findings of this study add to the literature on the STEM gender divide and confirm that numerous challenges still exist in creating a more equal gender representation among the STEM workforce (Xu, 2016).

References

Aud, S., Hussar, W., Johnson, F., Kena, G., Roth, E., Manning, E., Wang., Zhang, J. (2012). *The condition of education 2012*. Institute of Education Sciences, U.S. Department of Education, https://nces.ed.gov/pubs2012/2012045.pdf

Battista, M. T. (1990). Spatial visualization and gender differences in high school geometry. *Journal for Research in Mathematics Education*, 47-60.

Blickenstaff, J. C. (2005). Women and science careers: leaky pipeline or gender filter? *Gender and Education*, *17*(4), 369-386.

Bretz S. L. (2001). Novak's theory of education: Human constructivism and meaningful learning. *Journal of Chemistry Education*, *78*, 1107.

Ceci, S. J., & Williams, W. M. (2007). *Why aren't more women in science. Top researchers debate the evidence*. Washington, DC: American Psychological Association.

Cheryan, S., Ziegler, S. A., Montoya, A. K., & Jiang, L. (2017). Why are some STEM fields more gender balanced than others? *Psychological Bulletin*, *143*(1), 1–35.

Connors-Kellgren, A., Parker, C. E., Blustein, D. L., & Barnett, M. (2016). Innovations and Challenges in Project-Based STEM Education: Lessons from ITEST. *Journal of Science Education and Technology*, *25*(6), 825-832.

Cross, S. E., & Madson, L. (1997). Models of the self: self-construals and gender. *Psychological bulletin*, *122*(1), 5.

Crowley, K., Callanan, M. A., Tenenbaum, H. R., & Allen, E. (2001). Parents explain more often to boys than to girls during shared scientific thinking. *Psychological Science*, *12*(3), 258-261.

Dabney, K. P., Tai, R. H. (2014). Factors Associated with Female Chemist Doctoral Career Choice Within the Physical Sciences. *J. Chem. Educ*, *91*(11), 1777-1786.

De Vellis, R. F., & Dancer, L. S. (1991). Scale development: theory and applications. *Journal of Educational Measurement*, *31*(1), 79-82.

Diekman, A. B., Steinberg, M., Brown, E. R., Belanger, A. L., & Clark, E. K. (2017). A goal congruity model of role entry, engagement, and exit: understanding communal goal processes in STEM gender gaps. *Personality and Social Psychology Review*, *21*(2), 142-175.

Eccles J. S. (2009). Who am I and what am I going to do with my life? Personal and collective identities as motivators of action. *Educational Psychology*, 44, 78–89.

Freeman C (2004). *Trends in educational equity of girls & women: 2004* (No. NCES 2005016).

Frost, J. (2013). Regression analysis: How do I Interpret R-squared and assess the goodness-of-fit? http://blog.minitab.com/blog/adventures-in-statistics/regression-analysis-how-do-i-interpret-r-squared-and-assess-the-goodness-of-fit

Goan, S. K., & Cunningham, A. F. (2006). The investment payoff: A 50-state analysis of the public and private benefits of higher education. *American Academic*, *2*(1), 23-38.

Halpern, D. F., Benbow, C. P., Geary, D. C., Gur, R. C., Hyde, J. S., & Gernsbacher, M. A. (2007). The science of sex differences in science and mathematics. *Psychological Science in the Public Interest*, *8*(1), 1-51.

Hedman, L., Ström, P., Andersson, P., Kjellin, A., Wredmark, T., & Felländer-Tsai, L. (2006). High-level visual-spatial ability for novices correlates with performance in a visual-spatial complex surgical simulator task. *Surgical Endoscopy and Other Interventional Techniques*, *20*(8), 1275-1280.

Jackson, F. L., Charleston, L. J., Lewis, C.W., Gilbert, J. E., & Parris, W. P., (2017). Arizona's rising STEM occupational demands and declining participation in the scientific workforce: An examination of attitudes among African Americans toward STEM college majors and careers. *Texas Education Review*, *5*(2), 91-111.

Jeng, H. L., & Chen, Y. F. (2013). Comparisons of latent factor region means of spatial ability based on measurement invariance. *Learning and Individual Differences*, *27*, 16-25.

Kanny, M. A., Sax, L. J., & Riggers-Piehl, T. A. (2014). Investigating forty years of STEM research: How explanations for the gender gap have evolved over time. *Journal of Women and Minorities in Science and Engineering*, *20*(2).

Lindberg, S. M., Hyde, J. S., Petersen, J. L., & Linn, M. C. (2010). New trends in gender and mathematics performance: a meta-analysis.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child development*, 1479-1498.

Lubinski D., & Benbow C. P. (2006). Study of mathematically precocious youth after 35 years: uncovering antecedents for the development of math-science expertise. Perspective Psychological Science, DOI:1316–345 10.1111/j.1745-6916.2006.00019

Mau, W. C. J., Perkins, V. J., & Mau, Y. H. (2016). Gender and Racial Differences in Career Decision-making Dispositions of College Students Enrolled in STEM Majors.

Mintzes, J. J., Wandersee, J. H., & Novak, J. D. (Eds.). (2005). *Assessing science understanding: A human constructivist view*. Academic Press.

National Science Foundation. (2014). Integrated postsecondary education data system, 2013, completions survey. National Center for Science and Engineering Statistics: Integrated Science and Engineering Resources Data System (WebCASPAR). Retrieved from https://webcaspar.nsf.gov

Novak, J. D. (1993). Human constructivism: A unification of psychological and epistemological phenomena in meaning making. *International Journal of Personal Construct Psychology*, *6*, 167-193.

Quinn, David M., & North Cooc. (2015). Science Achievement Gaps by Gender and Race/Ethnicity in Elementary and Middle School: Trends and Predictors. *Educational Researcher*, *44*(6): 336-346.

Rutter, J., Standish, N., & Bull, G. (2016, March). Using Hands-on Learning Modules to Address Challenging Concepts in Electricity and Magnetism. In *Society for Information Technology & Teacher Education International Conference*(pp. 1510-1515). Association for the Advancement of Computing in Education (AACE).

Salzman, H. (2013). What shortages? The real evidence about the STEM workforce. *Issues in Science and Technology*, *29*(4), 58-67.

Sax, L. J. (2012). Examining the underrepresentation of women in STEM fields: Early findings from the field of computer science.

Schult, J., & Sparfeldt, J. R. (2016). Do non-g factors of cognitive ability tests align with specific academic achievements? A combined bifactor modeling approach. *Intelligence*, *59*, 96-102.

Shumow, L., & Schmidt, J. A. (2013). Academic Grades and Motivation in High School Science Classrooms Among Male and Female Students: Associations with Teachers' Characteristics, Beliefs and Practices. *J. Education Research*, *7*, 53-72.

Singh, K. (2007). *Quantitative Social Research Methods*. SAGE Publications, Thousand Oaks, CA.

Stansell, A., & Tyler-Wood, T. (2016, March). Reflections on Being New to Digital Fabrication. In *Society for Information Technology & Teacher Education International Conference* (pp. 2357-2361). Association for the Advancement of Computing in Education (AACE).

Stoeger, H., Duan, X., Schirner, S., Greindl, T., & Ziegler, A. (2013). The effectiveness of a one-year online mentoring program for girls in STEM. *Computers & Education*, *69*, 408-418.

Stumpf, H., & Eliot, J. (1995). Gender-related differences in spatial ability and the k factor of general spatial ability in a population of academically talented students. *Personality and Individual Differences*, *19*(1), 33-45.

Su, R., Rounds, J., & Armstrong, P. I. (2009). Men and things, women and people: a meta-analysis of sex differences in interests.

Tyler-Wood, T., Ellison, A., Lim, O., & Periathiruvadi, S. (2012). Bringing up girls in science (BUGS): The effectiveness of an afterschool environmental science program for increasing female students' interest in science careers. *Journal of Science Education and Technology*, *21*(1), 46-55.

Tyler-Wood, T., Knezek, G., & Christensen, R. (2010). Instruments for assessing interest in STEM content and careers. *Journal of Technology and Teacher Education*, *18*(2), 341-363.

Tyson W. (2011). Modeling engineering degree attainment using high school and college physics and calculus course taking and achievement. *Journal of Engineering Education*, *100*, 760–777

Ultanir, E. (2012). An epistemological glance at the constructivist approach: Constructivist learning in Dewey, Piaget, and Montessori. *International Journal of Instruction*, *5*(2), 1308-1470.

Unfried, A.; Faber, M.; Wiebe, E. Gender and Student Attitudes toward Science, Technology, Engineering, and Mathematics. The Friday Institute for Educational Innovation at North Carolina State University 2014, http://miso.ncsu.edu/wp-content/uploads/2014/08/AERA-2014-paper-Student-Attitudes-Toward-STEM.pdf

U.S. Bureau of Labor Statistics. (2015). STEM crisis or STEM surplus? Yes and yes. Accessed December 1, 2017, from https://www.bls.gov/opub/mlr/2015/article/stem-crisis-or-stem-surplus-yes-and-yes-1.htm

ISSN:2149-8504 (online)

U.S. Economics and Statistics Administration. (2017). STEM jobs: 2017 update. Accessed December 1, 2017, from http://www.esa.doc.gov/reports/stem-jobs-2017-update

Voyer, D., & Voyer, S. D. (2014). Gender differences in scholastic achievement: A meta-analysis. *Psychological Bulletin*, *140*(4), 1174.

Wang, M. T., & Degol, J. (2013). Motivational pathways to STEM career choices: Using expectancy–value perspective to understand individual and gender differences in STEM fields. *Developmental Review*, *33*(4), 304-340.

Wang, M. T., & Degol, J. L. (2017). Gender gap in science, technology, engineering, and mathematics (STEM): current knowledge, implications for practice, policy, and future directions. *Educational psychology review*, *29*(1), 119-140.

Wang, M.-T., Degol, J., & Ye, F. (2015). Math achievement is important, but task values are critical, tool: examining the intellectual and motivational factors leading to gender disparities in STEM careers. *Frontiers in Psychology*, 6, 36. http://doi.org/10.3389/fpsyg.2015.00036

Weinburgh, M. (1995). Gender differences in student attitudes toward science: A meta-analysis of the literature from 1970 to 1991. *Journal of Research in science Teaching*, *32*(4), 387-398.

Xu, Y. J. (2016). Aspirations and application for graduate education: gender differences in low-participation STEM disciplines. *Research in Higher Education*, *57*(8), 913-942.

Yager, R. E. (1991). The constructivist learning model: Towards real reform in science education. *The Science Teacher*, *58*(6), 52- 57

Zimmerman, E. L. (2016). 2D and 3D fabrication devices: Can they improve spatial reasoning skills in children?(Order No. 10307634). Available from Dissertations & Theses @ University of North Texas. (1871546915). Retrieved from https://libproxy.library.unt.edu/login?url=https://libproxy.library.unt.edu:2165/docview/1871546915?accountid=7113

ISSN:2149-8504 (online)

Journal of Research in STEM Education

Vol 4, No 2, December 2018, 193-212

RESEARCH REPORT

Curriculum and Instruction at Exemplar Inclusive STEM High Schools

Erin Peters-Burton[a1], Ann House[b], Ed Han[c], Sharon Lynch[d]

[a]*George Mason University, USA;* [b]*SRI International, USA;* [c]*Kipp DC, USA;* [d]*George Washington University, USA*

Abstract: *In recent years, prominent organizations have released large-scale policy reports on the state of science, technology, engineering, and mathematics (STEM) education in the United States, with particular emphasis on curricula and instructional practices. The purpose of this paper was to examine the curriculum and instruction occurring at high performing STEM-focused high schools that have no academic conditions for student admission. This study conducted a cross-case analysis across eight case studies of contextually different but well-regarded inclusive STEM high school. Common themes that emerged included different hierarchical levels of design and implementation (classroom-level, cross-cutting school level, school-wide) as well as responsive design of curriculum and instruction. Unique contextual differences are discussed as well as implications for replication of inclusive STEM school design.*

Keywords: Interdisciplinary approach, instruction, curriculum reform, inclusive stem high schools, cross-case analysis

Introduction

In recent years, prominent organizations including the National Research Council (NRC, 2011, 2012), the President's Council of Advisors on Science and Technology (PCAST, 2010a), and the National Academy of Education (NAEd, 2009) have released large-scale policy reports on the state of science, technology, engineering, and mathematics (STEM) education in the United States. There has been a particular focus on STEM curricula and instructional practices, with a push for a broad re-examination of the American system of teaching biology, chemistry, physics and, occasionally, earth science (Banilower et al., 2013). One recent notable effort to marshal STEM reform efforts was the NRC's (2012) Framework for K-12 Science Education, which laid the foundation for states to develop new K-12 science standards, called the Next Generation Science Standards (NGSS, 2013). These standards represent an attempt to better integrate science practices, crosscutting science concepts, and disciplinary core ideas across scientific disciplines to provide a stronger and more engaging foundation in science knowledge and skills for students.

Published data in the 2012 National Survey of Science and Mathematics Education (Banilower et al., 2013) demonstrate the need for these curricular and instructional reform efforts. Perhaps not surprisingly, these data indicated that the traditional science domains of biology, chemistry, and physics were treated as siloed disciplines in the majority of American high schools. Whereas 98% of high schools offered biology/life

[1] Corresponding author. George Mason University, Fairfax Campus, Thompson Hall 1401, 4400 University Dr. MS 6D2 Fairfax, VA 22030, E-mail: epeters1@gmu.edu

Peter-Burton, E., House, A., Han, E., & Lynch, S. (2018). Curriculum and Instruction at Exemplar Inclusive STEM High Schools. *Journal of Research in STEM Education*, *4*(2), 193-212.

ISSN:2149-8504 (online)

science courses, 94% offered chemistry courses, and 85% offered physics courses, only 68% of high schools offered "integrated science" courses, a number that is likely significantly inflated due to the inclusion of "general science" and "physical science" courses typically taken by students who do not intend to study science formally past high school (Banilower et al., 2013, pp. 54-55; NAEd, 2009).

Additionally, direct whole-class instruction by the teacher was the most commonly reported strategy in high schools, with 95 percent of both science and mathematics teachers using such activities at least once a week (Banilower et al., 2013, pp. 76, 81). By comparison, only 18 percent of science teachers employed project-based learning activities (p. 76). What was similarly rare for high school science and mathematics students was having the opportunity to attend presentations by guest speakers focused on science/engineering or mathematics in the real-world workplace. According to the survey, 51 percent of high school science teachers and 78 percent of high school mathematics teachers reported never using such activities in their classes (pp. 77, 82).

The desire for more interdisciplinary STEM curricula and reform-based STEM instructional practices is becoming increasingly tied to a push to increase the number of STEM-focused schools at all grade levels (NRC, 2011; PCAST, 2010b). The hope is for such schools to experiment with and serve as testing grounds for innovative STEM curricula and instructional approaches, rather than merely providing more advanced STEM instruction (PCAST, 2010a). Such innovations could lead not just to increased student achievement, but also to enhanced student engagement in STEM for students from minority and high-poverty communities, leading to a broader and more equitable participation in STEM majors and careers by student groups traditionally underrepresented in those fields (PCAST 2010a, see p. 111). This particular goal of broadening participation has stimulated the development of a particular kind of STEM-focused schools, the inclusive STEM-focused high school (NRC, 2011). These schools aim to provide more rigorous STEM curricula, increased STEM instructional time, increased resources for STEM education, and more prepared STEM teachers than are frequently seen in traditional high schools.

Purpose and Objectives

The purpose of this paper was to examine the curriculum and instruction occurring at high performing STEM-focused high schools in the United States that have no academic conditions for student admission. This paper is part of a larger study called Omitted for Blinding which explored the characteristics of a set of eight exemplary inclusive STEM-focused high schools (ISHS) across the United States. The intent of the larger study was to develop rich, descriptive case studies of each ISHS, leading to an evidence base for identifying the critical components of these schools (described further in Table 1; Authors & Colleagues, 2017). The study also included cross-case analyses to highlight the commonalities and explore the differences in these components across the ISHSs, which include curriculum and instruction (Stake, 2006; Yin, 2003). The purpose of this study was to investigate the curriculum and instruction provided at the ISHSs. We felt that the closer examination of curriculum and instructional practices at these schools could provide insight on school design and implementation features that enabled the teaching of STEM content designed for all students to graduate college STEM ready.

Specifically, this analysis concentrated on the "STEM-Focused Curriculum" and "Reform Instructional Strategies and Project-Based Learning" critical components, which were (Author & Colleagues, 2017) defined as:

> *STEM-Focused Curriculum. Strong courses in all four STEM areas, or, engineering and technology are explicitly, intentionally integrated into STEM subjects and non-STEM subjects (Atkinson, Hugo, Lundgren, Shapiro & Thomas, 2007; Colleagues & Author, 2008; Scott, 2009).*

> *Reform Instructional Strategies and Project-Based Learning. STEM classes emphasize instructional practices/strategies informed by research and immersing students in STEM content, processes, habits of mind and skills (Atkinson et al., 2007; Colleagues & Author., 2008; Scott, 2009). Opportunities for project-*

based learning and student production are encouraged, during and beyond the school day. Students are productive and active in STEM learning, as measured by performance-based assessment practices that have an authentic fit with STEM disciplines (Atkinson et al., 2007; Colleagues & Author 2008; NRC, 2004, 2005, 2010; Subotnik, Tai, Rickoff, & Almarode., 2010; Scott, 2009).

The analysis examines what is taught in these schools: the range of STEM offerings, the rigors of those offerings, and the extent to which STEM permeates the school mission, informal activities, and non-STEM subjects. Furthermore, this paper describes how STEM is taught in the ISHSs: the range of instructional practices seen in these schools and the learning opportunities fostered through those strategies.

Ultimately, the aim is to unpack the curriculum and instructional practices crucial to the design and implementation of well-established inclusive STEM schools in order to provide insights that can be valuable for STEM education and pedagogy in schools across the country.

In light of these objectives, the research questions addressed by this paper are:

1. What characteristics of STEM curriculum and instructional practices are common across eight ISHSs?
2. What distinguishing features or unique contextual characteristics of STEM curriculum and instructional practices exist across these schools?
3. What are the various contextual affordances and constraints that influence the design and implementation of STEM curriculum and instructional practices across these schools?

Theoretical Framework

The theoretical framework for the study draws on the concept of opportunity structures first used by Kenneth Roberts (1968) in studies of the conditions that might lead an adolescent towards criminal activity rather than a pathway to a productive career if certain positive avenues of development, such as educational opportunities, were blocked. Education is an important opportunity structure (Eisenhart et al., 2015). In the 21st century, STEM education is especially salient. This study adapts the idea of education as an opportunity structure and considers the full range of deliberate or inherent supports and guidance that ISHSs may employ to help students from groups underrepresented in STEM to move into STEM college majors, jobs, and careers. With this theoretical framework as the foundation for the study, the research team conducted studies of successful ISHSs to compile a set of candidate critical components that may work in conjunction to provide a strong STEM education to students. The 14 critical components (Table 1) represent working hypotheses for the basis of a theory of action for ISHSs, supported by the existing body of research on inclusive and selective STEM-focused high schools (Author & Colleagues, 2014; Author & Colleagues, 2017).

Table 1.

Critical Components for Inclusive STEM High Schools

STEM-Focused Curriculum
Reform Instructional Strategies and Project-Based Learning
Integrated, Innovative Technology Use
Blended Formal/Informal Learning Beyond the Typical School Day, Week, or Year
Real-World STEM Partnerships
Early College-Level Coursework
Well-Prepared STEM Teaching Staff
Inclusive STEM Mission
Administrative Structure
Supports for Underrepresented Students

Dynamic Assessment Systems for Continuous Improvement
Innovative and Responsive Leadership
Positive School Community and High Expectations for All
Agency and Choice

*See Lynch et al., 2017 for detailed description of components not related to this paper.

Among the fourteen critical components, this paper focuses on the first two listed, (a) STEM-focused curriculum and (b) the use of reform instructional strategies and project-based learning. While the remaining components are seen as critical to effective inclusive STEM schools, the components of curriculum and instruction affect the core of the educational experience (Elmore, 1996; Mehta & Cohen, 2017). Curriculum is critical since it is the foundation of classroom instruction, and coherent curricula and standards are key indicators of successful K-12 STEM schools (Atkinson et al., 2007; Colleagues & Author, 2008; NRC, 2011; Scott, 2009; Subotnik et al., 2010). Instruction is also a focus of this analysis, since effective STEM instruction is important because the ways students access and engage with content is as influential in student learning as the content itself (NRC, 2011).

Conceptualization and implementation of effective STEM education requires more than merely the emphasis on more science and mathematics courses (Lamberg & Trzynadlowski, 2015). Rather, the integration of STEM should promote interdisciplinary lessons which help to support interconnections not only among the STEM subject matter (Eleftheria, Sotiriou, & Doran, 2016), but also connects in-school learning to real-world situations (Breiner, Harkness, Johnson & Koehler, 2012; Johnson, 2013; Rennie, Venville, & Wallace, 2012; Roehrig, Moore, Wang & Park, 2012). Integrated STEM education has been shown to increase high school students' learning in physics and pursuit of postsecondary STEM education (Fang, 2013). Even elementary students who experience rigorous and integrated STEM instruction had improved content knowledge and process skills (Cotabish, Dailey, Robinson, & Hughes, 2013).

In addition to integrated content, STEM education has been found to have positive impacts when it is connected to real-world STEM practices. The National Research Council (NRC, 2011) and the President's Council of Advisors on Science and Technology (PCAST, 2010a) both emphasize that effective STEM instruction aims to foster a deeper engagement with the sciences and mathematics domains by providing personal and team-oriented opportunities for students to be involved in real-world STEM practices. In addition, explicitly providing real-world connections for students in curriculum and instruction have demonstrated increases in interest, outcome expectations, goal setting, and content knowledge (Grubbs & Deck, 2015; Hiller & Kitsantas, 2014).

Real-world connections make instruction more authentic and meaningful to students. Instruction that is set in an authentic context also promotes 21st Century skills, such as creativity, communication, collaboration and critical thinking. Student-centered teaching techniques that involve student collaboration and communication have been shown to be key to student motivation, persistence, and positive social interactions (Lamb, Akmal, & Petrie, 2015; Morrison, Roth-McDuffie & French, 2015). In addition, Twenty-first Century skills are not only important to pursuing STEM careers (Lent, Brown, & Hackett, 1994; Mohr-Schroeder et al., 2014), but are important skills that are used in daily life (Carroll, 2015). van Breukelen, Smeets and de Vries (2015) found that explicit teaching and scaffolding during authentic design challenges strengthened both content knowledge and skill performance.

The National Research Council (NRC, 2011) and the President's Council of Advisors on Science and Technology (PCAST, 2010a) have also both emphasized that effective STEM instruction aims to engage students within and beyond the classroom to include partnerships with STEM professionals. Community partnerships are one way to extend STEM instruction beyond the classroom, and interaction with STEM professionals through school activities have instilled a high degree of autonomy and sense of responsibility in students (Watters & Diezmann, 2013). Participation in out of school STEM learning have had a positive impact on in-school science and mathematics scores (Chung, Cartwright & Cole, 2014), STEM career interest (Reynolds, Yazdani, & Mazur, 2013), and choice of STEM major (Sahin, 2013). Students from groups typically underrepresented in STEM benefit from authentic experiences that blend in school and out of school STEM instruction in areas such as increasing positive attitudes toward STEM (Naizer, 2014), pursuit of STEM careers (Denson, Austin, Hailey, & Hauseholder, 2015; Rahm & Moore, 2015), and environmental engagement (Oyana et al., 2015). This paper explores the extent and variety of ways that STEM curriculum and instruction are present in eight case study ISHSs.

Methods

Before cross-case analyses were conducted, individual case studies of the schools were composed (Stake, 2006). In this section, we first describe an abbreviated version of the methods for the larger individual case studies to explain the actions taken to reduce threats to validity for the source material. The full description of the methodology can be found at Author and Colleagues (2018). We then describe the methods for the curriculum and instruction cross-case analysis.

Individual Case Studies

Schools in this study needed to meet three criteria: (a) identify as a STEM-focused school, (b) have open admissions that were not dependent on prior academic performance, and (c) serve students in grades 9-12. The schools could use a random chance lottery if they had more interested students than available seats. A panel of experts in STEM education recommended 35 schools to the research team. Of these 35 schools, 18 were eliminated because they were not STEM focused or did not allow open enrollment. Six of the schools were eliminated because they were new and did not yet serve 9-12 grades. Eight of the schools from the remaining 11 were selected for their geographic diversity and wide variety of educational models. Table 2 lists the eight case study schools, their location, and a brief description of each school. We have obtained permission to use the school's actual names.

Table 2.
Description of eight case study schools

School	Location	Brief Description
Chicago High School for Agricultural Sciences (CHSAS)	Chicago, IL	Established in 1985, CHSAS is a public magnet high school providing career-technical education in agriculture.
Denver School of Science and Technology: Stapleton High School (DSST)	Denver, CO	Focused on intensive college preparation, DSST was the first school in the public charter DSST STEM network.
Dozier-Libbey Medical High School (DLMHS)	Antioch, CA	Opened in 2008, DLMHS is a public school located in Antioch, California, and has a focus on health and medicine.
Gary and Jeri-Ann Jacobs High Tech High School (HTH)	San Diego, CA	Part of a network of public charter schools, HTH engages students in project-based learning and internship experiences.

ISSN:2149-8504 (online)

Manor New Tech High School (Manor)	Manor, TX	Located near Austin, Manor is a district high school and a member of the New Tech Network of schools using project-based learning.
The Metro Early College High School (Metro)	Columbus, OH	Metro is a semi-public, non-charter, privately funded high school located on the campus of The Ohio State University and offers students the opportunity to take Ohio State University courses.
Metro Urban Science Academy (USA)	Boston, MA	USA is a science-focused Boston public high school, which is accessible to all students living in the city. The school was originally part of an initiative to have smaller schools in urban areas.
Wayne School of Engineering (Wayne)	Goldsboro, NC	Wayne is a public high school opened in 2007, providing a focus on STEM disciplines.

*See Lynch et al., 2017 for detailed description of participating school contexts and related student outcomes.

Before each site visit, the research team conducted a document analysis of materials found on the internet such as admission applications, mission statements, and recruitment materials of each of the eight selected schools as well as interviewing a school-based coordinator about the critical components found at the school. The visits to the ISHSs consisted of a four-day schedule for six researchers, who formed three teams of researcher pairs. A sample schedule with all the events of an ISHS visit can be found in Table 3.

Table 3.
Data Collection Activities at Site Visit to Manor New Tech High School (Lynch et al., 2017)

Classroom observations

- STEM Classes (Phylgebrics, Biology, Geometry, Chemistry, Engineering, Pre-Calculus/Science Research and Development)
- Non-STEM Classes (Spanish II A, ELA Humanities, English/Economics, English 3/American History)

Focus Groups

- Teachers (Teachers of Engineering, Mathematics, Science, Technology, afterschool clubs)
- Students (12th Graders on Informal learning, 11th Graders on Science and Math, 10th Graders on Technology and Engineering, 9th graders on the school overall)
- Parents

Interviews

- School Personnel (School District, Dean of Students, Principal, Teacher Mentor/Coach)
- Non-School Personnel (Business Partners, UTeach Representative, Student Alumni)

Other Activities

- School Tour
- School-wide circle time
- Teacher-led lesson development discussion
- Afterschool Key Club
- Afterschool Robotics club
- Student Astronomy Presentations Panel

Coding. The data collection activities before and during the site visit resulted in hundreds of pages of observation notes, near verbatim focus groups and interview notes, and school-related artifacts. Two researchers coded independently and discussed the codes until there was consensus with all coding for the documents. Coding of the documents was both deductive, using the critical component definitions as a code book (the first 10 components listed in Table 1), and inductive, coding for any emerging themes that were deemed meaningful to the study (which emerged as the last four components listed in Table 1). The final case study report was reviewed and edited by the full site visit team, and reviewed by the school.

Cross-Case Analysis

The eight case studies, which were rich, informative descriptions of the school critical components ranging from 61 to 102 single-spaced pages each, were used for a Type 1 (Stake, 2006) cross-case analysis for this study. The text was open coded for any meaningful statements with no codebook used for this process. The codes were then compiled into a conjecture matrix with notations. Originally there were 35 codes in the conjecture matrix, and codes that were similar were collapsed into 23 broader codes that represented the major codes as seen in Table 4. The categories were subsumed into four overarching themes: (a) classroom implementation, (b) school-level learning opportunities, (c) school-wide design, and (d) responsive design.

Table 4.

Codes, categories and themes for curriculum and instruction components

Theme	Category	Code
Classroom Implementation	School focuses on students' learning the content to the level of mastery	• differentiation strategies used • data systems used for feedback on individual student learning • supports and higher opportunities provided to keep students in heterogeneous classes
	School extensively uses non-traditional curricular content sources	• teacher generated projects • community college courses • Project Lead the Way • building curriculum from various media (e.g., Kahn academy) • rarely use textbooks
Cross-cutting School Level Learning Opportunities	Collaborative group projects are required in a variety of formats & foci	• classroom activities • projects required outside of class • integrated project/problem based learning • Advisory projects
	Students participate in summative or culminating experiences	• gateway projects • capstone experiences • cohesive and reflective experiences
	School frequently uses interdisciplinary courses and/or projects	• range of combinations (cross grade, cross class, whole school) • range of frequency (wall to wall, several in a year) • mathematics less involved
School-wide Design	Curriculum and schedule are designed to provide academic rigor	• grad requirements more rigorous than state requirements • school offers college prep courses (including pre-calculus) • school schedule allows for more credit accumulation • students have access to virtual and college classes

ISSN:2149-8504 (online)

	Nearly all students take high rigor courses	• schools offer few electives • most students take college prep courses (including pre-calculus) • students take courses as a grade cohort
	Schools offer engineering / design thinking	• offered through courses and/or a whole school theme
	Emphasis on real world connections & 21st century skill building	• collaboration • problem solving • information and media literacy • self-directed learning
	Strong teacher collaboration	• shared course or project design • shared student assessment • engagement in school planning & design
Responsive Design	Schools use data-driven decision making to improve instruction	• used at classroom level • used at whole school level
	Schools are challenged with the entry level skills of incoming 9th graders	• typically lower in mathematics

The team then examined the data and rated the prominence and utility of each of the 12 categories at each school. The ratings were made on a four-point rubric. For prominence, a 0 indicated no evidence for the category at the school; 1, the category was observed but not prominent; 2, the category was present, obvious, and an inherent aspect of the school operation; and 3, the category was a major design feature of the school. For utility, a 0 indicated no use of the category at the school; 1, the category was used in minor ways; 2, the category was used in frequently but not widely or widely but not frequently; and 3, the category was used frequently and widely across the school.

Guided by the ratings of utility and prominence, the 12 categories were developed narratively in the paragraphs of the cross-case analysis. The narrative was member checked with the authors of the original case study and adjusted to represent consensus of understanding among all authors.

Findings

The eight schools were generally strong in all the categories analyzed, consistent with their selection as exemplar school models and confirming the fit of the categories used in this analysis. Ratings for each category within each school are presented in Table 5. The table shows there was variation in how the schools addressed each theme, yet the schools were largely consistent in their use of these curricular and instructional elements. The variations demonstrate design and contextual choices rather than issues of quality.

Table 5.

Average prominence and utility ratings for coding themes

Heading & Theme	School A	School B	School C	School D	School E	School F	School G	School H
Classroom Implementation								
School focuses on students' learning the content to the level of mastery	3	3	3	2	1	3	3	1
School extensively uses non-traditional curricular content sources	3	3	2.5	3	3	3	1	2
Cross-cutting School Level Learning Opportunities								
Collaborative group projects are required in a variety of formats & foci	2.5	3	3	3	3	2.5	2	3
Students participate in summative or culminating experiences	1.5	3	3	3	3	2.5	0	3
School frequently uses interdisciplinary courses and/or projects	2.5	2.5	3	3	3	3	3	3
School-wide Design								
Curriculum and schedule are designed to provide academic rigor	2	3	3	3	3	3	3	3
Nearly all students take high rigor courses	3	3	3	3	2.5	3	1.5	2
Schools offer engineering / design thinking	1	2.5	2.5	3	3	3	1	3
Emphasis on real world connections & 21st century skill building	3	2.5	3	3	3	2.5	3	2
Strong teacher collaboration	2.5	3	3	3	3	2	3	3
Responsive Design								
Schools use data-driven decision making to improve instruction	3	3	2.5	3	2.5	2.5	2.5	2
Schools are challenged with the entry level skills of incoming 9th graders	3	2.5	3	3	3	2	3	3

Note: Participating schools requested anonymity on prominence and utility ratings

The remainder of this paper will explain how the categories within the four themes were enacted and how they varied across the schools. The four themes used to organize the discussion, from smaller to larger, are (a) classroom-related STEM opportunities, (b) cross-cutting school level STEM learning opportunities, (c) school-wide design for STEM learning and (d) systems and practices schools use to respond to needs in STEM curriculum and instruction. The relationship among the four headings will be explained in the discussion section of this paper.

Classroom-related STEM opportunities

Mastery learning. A significant feature across the schools was supporting mastery learning by providing multiple opportunities for students to complete learning tasks, as well as timely and meaningful feedback. Teachers offered differentiated learning strategies and used data systems for feedback on individual student learning to improve the supports they provided to keep students in heterogeneously leveled classes. Students who do not initially meet mastery standards were given the opportunity to try again and retake the assessments. This was not seen by students as failure, but as part of the learning process. A student at DLMHS stated,

> This school is harder because we have harder classes but we have the ability to retake. Other schools don't have that option. This school is focused on mastery. This school is really about giving you chances, letting you have the ability to retake, and just get better at it instead of just saying you didn't do well on the first time so you're done. This school wants you to actually learn the concept.

Five of the eight ISHSs had school-wide data systems to monitor mastery learning. DSST perhaps had the most detailed data system, which entailed a list of objectives to be met over the course of a year. Once a teacher observed a student mastering that objective three times, they recorded this in the online system and the student moved on to other objectives. Other schools, such as Metro, USA, CHSAS, and DLMHS used electronic grading programs to record student mastery progress.

Non-traditional curricular content resources. As a group, these schools sought out non-traditional curricular content sources as a basis for classroom instruction and rarely used traditional textbooks. The sources of curriculum used in ISHSs included teacher generated projects, collaborations with higher education faculty, adaptations of Project Lead the Way curriculum, and internet-based media such as Khan Academy.

The schools expected their teachers to be designers of curricula, with minimum reliance on published textbooks. The schools felt this teacher-designed curriculum and instruction was more motivating and engaging for students and helped to keep curriculum and instruction innovative. At HTH, teachers integrated topics across subject matter and co-taught these courses. Since the topics and teacher pairings changed from year to year, the teachers were proficient at designing original curriculum while still meeting state standards.

Cross-cutting School Level STEM Learning Opportunities

Collaborative group projects. Seven of the eight schools used collaborative group projects to provide authentic learning opportunities for students. The exception was DSST, which did not have a school-wide effort to promote projects. Rather, DSST teachers individually taught using projects in their classroom, especially in required engineering classes.

The formats of the school-wide collaborative group projects took a variety of forms. Manor and HTH adopted project-, problem-, and challenge-based learning as the format for all curriculum and instruction. One instance was a HTH unit titled "Sound Mind, Sound Body," which integrated naturalist writing and human body systems, and used weekly hikes to contextualize both physical training and exploration of the humanities. CHSAS also used collaborative group projects in students chosen agriculture pathways, integrating mathematics, science, history and language arts content in purposeful ways. Examples included exploring the chemistry behind horticulture, connecting mathematics and psychology principles to commodity prices, and applying human geography to dairy markets in the agricultural finance course. The principal, Bill Hooks, explained,

> [Teachers] try to make these interdisciplinary connections. We all brought down our curriculum maps a few years ago and said…If you're studying the Great Depression in U.S. history and you're reading Grapes of Wrath in English let's do those simultaneously. In our agriculture class, let's cover the impact on soil erosion during the Dust Bowl years.

Summative and culminating projects. Another school-level learning opportunity found across all of these exemplar schools were projects that engage students in authentic learning experiences that serve as summative or culminating experiences such as gateway projects, capstone experiences, and other assignments that were designed for cohesion across and reflection on learning experiences. An example of summative projects was seen at HTH, where students compiled and presented their best work in personal digital portfolios at the end of their HTH career. The digital portfolios provided a comprehensive look at each student's work and learning, and included a personal statement, resume, and work samples. Students updated their digital portfolios each semester, documenting and reflecting on their learning over time.

Some schools used community connections to help students apply their STEM knowledge to real world contexts. At Manor, students were required to complete a Capstone Project Senior Year in order to graduate. Past capstone efforts included community service projects such as producing a 5K run to benefit a college scholarship, designing and selling bracelets for a college scholarship for undocumented children, and creating a documentary to create an awareness of local public finance malfeasance. All students had professional mentors outside of school, whom the students identified and engaged in their projects. The mentors helped students understand the professional skills and knowledge they needed to accomplish their goal.

Interdisciplinary courses or projects. Six of the eight case study schools had the requirement of interdisciplinary courses and/or projects. The use of interdisciplinary courses and projects at the schools brought students together across grade levels, across courses, or even at the whole school level. Such programs ranged in frequency – Metro assigned a whole school, cross-grade project once each year, while Manor used projects across subjects throughout the school year. Some interdisciplinary projects combined two classes, while others combined a larger range of subjects. DLMHS assigned a project across classes in Medical Ethics, English, Physics and Government, in which students chose a physical disability and students in this medical

ISSN:2149-8504 (online)

focused high school designed an innovation to improve the lives of those living with such disabilities.

Manor and HTH both used a full-time project-based learning (PBL) instructional approach. At Manor, most courses offered for those in 11th and 12th grades were cross-disciplinary including Physics/Algebra II, Scientific Research and Design/Statistics, and Environmental Science/Pre-Calculus. These courses were taught by pairs of teachers in block periods. At HTH, most courses fully integrated two subject areas. An integrated humanities and biology course at HTH was structured around the theme of human experience in the natural world, covering both human physiological systems as well as naturalist writing. Mathematics, however, was the only field not included in this course pairing system. HTH school leaders felt strongly that the mathematics curriculum was diminished by forcing it to be integrated with other subjects, and believed that students were better prepared for college mathematics by not integrating it with other subjects.

Interdisciplinary projects were also offered at Metro, which used semester-long design challenge projects, in which students from all four grade levels were grouped to explore topics such as sustainable farming and living in their local region. Metro also had juniors participate in semester-long "learning center" courses, which combined high school courses with courses at Ohio State University (OSU) to explore Human Body Systems or Energy, Environment and Economics.

Of a shorter duration, USA offered week-long interdisciplinary units designed to make learning relevant to students. At this school, the 10th grade students explored housing conditions of migrant workers with a science component (energy efficiency), a mathematics component (cost), and a communication component (Spanish class). Another week-long project had 10th grade students take the role of video game developers and design a video game for a teenage brain. Students wrote computer code for their game, explored relevant science and chemistry concepts, and wrote a business proposal for their game. The motivations and payoffs for using projects lasting a week, a semester or a year included reinforcing the curriculum by circling back to ideas already taught, providing real world applications for STEM content knowledge and skills, as well as building interdisciplinary connections.

School-wide Design for STEM opportunities

Rigorous curriculum and schedule. The eight schools in this study used several strategies in class scheduling and class requirements to ensure all students at their school were held to high expectations. One strategy used was to design all students' graduation requirements more rigorous than state graduation requirements. Often these additional requirements involved courses in advanced science, mathematics, technology or engineering. All of the schools required that students complete up to at least the level of pre-calculus for their mathematics credits. To meet these high expectations, schools used innovative course scheduling. Aimee Kennedy, Chief Academic Officer at Metro explained, "in a regular school, 9th graders take Algebra I, but [many of those students] can never get through pre-calculus in that system." Metro addresses this issue by placing 9th and 10th grade students in intensive, one-semester-long courses that cover what normally would take two semesters in most high schools. Students enroll in four of these intensive academic classes each semester, in addition to a six-week January term between the two semesters. This way, students efficiently cover required courses and earn more than the average number of high school credits each year. Similarly, Manor used a trimester system, which allowed students to accrue 1.5 times the number of credits in a single year as schools on a two semester system.

Certainly some students in more typical, comprehensive high schools take college preparatory offerings and other courses beyond the basic graduation requirements. The significance of the schools in this study is that these requirements are held for all students, no matter what skill level or preparation they bring as incoming 9th graders. The requirements are met through supports provided by the schools. At Manor, where there were a number of students scoring below expectations on state mathematics assessments, the school offered an additional basic mathematics course in its trimester system so that students could still be ready for Calculus by senior year.

ISSN:2149-8504 (online)

The one school that did not clearly fit this theme was Boston USA, which was forced by its district to "absorb" another school which was underperforming two years before the site visit. At the time of the visit, USA strongly encouraged all students to take at least one AP class before graduation, yet the school staff acknowledged that "we need more rigor and we are constantly working on that. It is not a subject we take lightly."

Engineering/design thinking. Five of the eight schools held a strong focus on engineering or design thinking and required at least one engineering course. At Wayne, all incoming 9th graders took honors Engineering the Future and honors Applications of Science, both courses designed by school staff. After the freshman courses, Wayne engineering courses were offered in partnership with engineering instructors from the local community college. Beyond classes, the engineering design process was also incorporated into most of the courses taught at Wayne. The Wayne Principal explained, "No one should just be satisfied doing something one time and turning it in. It's always tinkering with it and making it better. That's kind of what we want to teach our kids." Engineering and design thinking were also prominent at other schools. HTH had a strong design thinking focus, Metro's engineering teachers were trained and certified by Project Lead The Way (PLTW), and Manor offered a two course PLTW-based engineering sequence as well as electives in digital electronics and a robust Robotics Club.

Engineering as a school theme or course of study was less prominent in the remaining schools, but these schools still provided some inquiry experiences for students. Even DLMHS, a medical focused high school that offered no engineering courses, did offer design thinking experiences. In each of their four years, students completed long term interdisciplinary projects. CHSAS had an agriculture focus, but the hands-on aspect of the curriculum provided a real world practicality. A chemistry teacher explained, "in a cookbook-lab, the logic is laid out. With inquiry like this … they can go back and review decisions or errors they may have made for next time. If you're doing research in a lab, you don't just do something to figure it out. You talk about it with your team and have a plan in place. You still make mistakes and that's ok."

Science was a major focus at USA, and while they explored offering engineering, they ran out of resources and struggled with staff capacity. The one place in which engineering appeared was in the context of science, where one teacher reported including the topics of bioengineering and molecular engineering in the AP Biology course.

Emphasis on real-world connections. Across the eight schools, a consistent theme was supporting students to face challenges outside of school. Toward this end, these schools helped students build work and metacognitive skills including collaboration, problem solving, information and media literacy, and self-directed learning. The PBL schools (Manor and HTH) as well as the schools with significant project-based learning opportunities (DLMHS and CHSAS) achieved this through shared language used by teachers and staff throughout the school. DLMHS held students to school wide learning outcomes known as VITAL Signs, and requiring every student to be Verbal, Intellectual, Technological, Academic, and a Leader. Seniors at DLMHS were required to present and defend a portfolio of their work that demonstrated their use of VITAL Signs over their four years of study. Students and staff at Metro also had quick access to their Metro Habits of Mind (Effective Communicators, Inquiring Learners, Active and Responsible Decision Makers, Effective Collaborators, Critical Thinkers, and Engaged Learners) through posters and conversations throughout the school. Each year, students participated in schoolwide Design Challenges that were designed to foster "interdisciplinary learning as well as the creativity, critical thinking, and collaboration skills that make up" these habits.

Secondly, these schools also had strong connections to partners outside of schools and opportunities to apply concepts students were learning in authentic settings. DLMHS relied upon an advisory committee of representatives from local hospitals and health care settings; HTH frequently invited scientists, engineers, and other STEM professionals to attend panels, give students feedback, or provide pre-project advice on design; USA used external partnerships including Urban Ecology Institute at Boston University, Bunker Hill Community College, and the Cloud Foundation to build and expand their curriculum. At DSST, the staff took a deliberate approach to balance the academic rigor of classes with application of STEM principles to the real world.

ISSN:2149-8504 (online)

Strong teacher collaboration. At five of the eight schools, teachers and school leaders described strong schoolwide teacher collaboration, supported by school culture and time regularly scheduled for this work. Teachers worked to help coordinate class learning goals, provide peer review for lessons, and conduct shared student assessment.

Other schools in the sample which did not have substantial co-teaching or shared projects still used structures within weekly or daily schedules for professional learning communities, common planning time, curriculum meetings, group reflection sessions, and group lesson tuning. At Wayne and Manor, group lesson tuning was done on a weekly basis, in which a teacher or group of teachers shared a lesson design and accompanying student work. Other teachers, within and outside of their discipline, provided feedback and discussion with the goal of improving student learning for that particular lesson. At DSST, where there were no cross-curricular projects or co-teaching, the staff had a strongly collaborative value and practices, in which teachers of similar courses worked toward the same standards and end-of-term exams, and teachers of sequential courses collaborated to ensure students were prepared for each subsequent course they took. Supporting these coordination goals were schedules which allowed for daily common planning time, twice monthly departmental meetings, and having regular time during the school day to plan together (Spillane, 2017).

Responsive Design

Data-driven decision-making. The ISHSs demonstrated the use of data-driven decision making, systems of coordinated teaching and management practices using student data to make informed decisions about instruction planning and management (Hamilton et al., 2009), at both the classroom level and at the school level. At the school level, data-driven decision making used student achievement data to inform choices made about curriculum and instruction. A prominent example of this was at DSST, which created highly flexible and adaptive instruction using student achievement data. Each fall and spring, staff used standardized assessments at the 9th, 10th and 11th grade levels to place students into performance bands so that instructors could target their similar needs. In addition, DSST teachers took two days after each trimester to analyze student performance data and design subsequent instruction that focused directly on particular student needs identified from the gap analysis. Metro used Measures of Academic Progress (MAP) testing to help place each incoming 9th grade student in the appropriate mathematics class. Metro had a Data Coordinator staff member who supervised MAP testing, student placement, as well as tracking student performance in courses. Metro also worked closely with OSU, their higher education partner, to track students' credits, grade point averages, and any successes or challenges faced in the college courses taken while at Metro, both to support students and to inform the level of rigor of their curriculum.

At the classroom level, many of the schools focused curriculum adaptation on the subject of mathematics. At DLMHS, USA, and Manor, the Principals noted that many students enter the school as 9th graders unprepared to achieve in mathematics. The schools used student assessment data to adapt courses to support struggling students. At USA, students were placed in appropriate mathematics courses based on the results of a pre-test, regardless of student status as 9th graders. At DLMHS, mathematics teachers used a repeated quiz system to assess student mastery of standards. While DLMHS did not use a school wide data system to drive instruction, the Principal explained that teachers adapted the curriculum to suit the students' needs:

> "Our math teachers actually took the Algebra curriculum and they broke it into concepts. As the teachers presented the concepts, they regularly tested the students. A student will be tested on every concept five times, so that if they haven't got it in the beginning and they start getting it, they can pass. Teachers rotated the concepts, so that "On a concept quiz there would be four or five concepts. For example, one quiz will cover concepts one through four. The next week will cover concepts two through five, followed by another quiz on concepts three through six, and then four through seven. So, they're tested on those repeatedly and then they can go back in, get more help, and take them over."

HTH used data to decide as a school to teach a stand-alone mathematics class because they noted that advanced mathematics was difficult to teach as integrated into the problem-based learning units. The Chief Academic Officer (CAO) felt strongly that the mathematics curriculum was diminished by forcing it to be integrated with other subjects. Though it was integrated at one time, the school made the decision to separate it based on past poor student performance in mathematics, parent feedback, and student feedback.

Challenges with incoming ninth graders. In light of the high expectations the schools had for students, all eight schools faced challenges with the entry level skills of incoming 9th graders, particularly in the subject of mathematics. Several schools addressed this challenge by using a flexible schedule. At DSST, students took two and sometimes three periods of mathematics or reading per day to develop their skills so that they were prepared for pre-calculus during their senior year. These students took extra core classes rather than taking electives. Metro and CHSAS focused on rigorous background courses in grades 9 and 10 before students took integrated application courses. USA scheduled two teachers to co-teach all course classes in 9th and 10th grade, effectively reducing the teacher-student ratio. As the USA principal stated, "I think having those classes at those two grade levels being co-taught makes a big difference in how our kids succeed, as it gives students the additional support necessary to successfully navigate through the transition from middle school."

Some of the schools addressed student support within the class structures. At DLMHS, teachers deconstructed the Algebra class, one of the most difficult for new students to pass, in to concepts and created smaller iterative cycles of assessment to pinpoint student needs which students could retake when they sought help in their deficient areas. HTH recruited the 11th grade students to mentor the 9th grade students. During 9th grade projects, teams are joined by 11th graders who give them advice as they progress through projects.

Some of the schools chose to overcome the challenge of student with lower entry level skills by preparing middle school students to function well in their high school settings. At the time of the visit, WSE was building a middle school in the same space as the high school and had instituted a 6th grade, with 7th and 8th grade being added each subsequent year. HTH also had an elaborate school system that included multiple elementary, middle, and high schools in addition to a graduate school for teacher training.

Discussion

Common practices across the ISHSs

While each school was unique in design, culture and resources, there were similar approaches to the shared goal of STEM success for students. The schools adopted a mission of preparing students for STEM college majors and careers requires rigorous preparation. The school schedule was purposefully designed for rigorous STEM learning (Cotabish, Dailey, Robinson & Hughes, 2013; Lamberg & Trzynadlowski, 2015) and success in these high-level courses was expected for all students attending the school, regardless of background, thus providing opportunity structures for all students. Through the use of non-conventional resources materials and partnerships, teachers created supports for students to succeed in STEM courses. This is consistent with the findings of Certo, Cauley, and Chafin, (2003), Eleftheria, Soririou, and Doran (2016), and Fang (2013) who found that challenging students with rigorous material through authentic, interdisciplinary learning experiences helped students value what they were doing in school and motivated them to master higher levels of content and skills. The ISHSs shared the goal of graduating students prepared for demanding studies of mathematics beyond levels to which typical comprehensive high schools aspire, even if additional coursework was required. In doing so, the schools created opportunities for students to pursue STEM as a career if they decided that route.

The schools in this study used innovative instructional approaches. By encouraging and supporting teachers to use student-centered techniques, collaboration in the classroom, frequent cycles of feedback to students, and summative or cumulative projects across all high school grades, these schools provided learning

ISSN:2149-8504 (online)

environments where students were expected to play an active role in their learning. Morrison, Roth-McDuffie, and French (2015) also found that student collaboration and social interaction were key in effective teaching and learning in a STEM school. These types of instructional practices are not often used, as less than half of American high school students report working in groups, and little class time is devoted to student-centered discussions (Cocoran, & Silander, 2009). ISHSs provided opportunity structures by helping students to manage their own learning and to become self-aware of their strategies for achievement.

The ISHSs in this study were purposefully designed to emphasize real-world connections and 21st Century skills such as communication, collaboration, problem-solving and self-directed learning through integrated subject matter. Teachers and administrators at these schools understood that academic capital is no longer built with how much content a person knows, but how to locate, evaluate, and apply knowledge to solve problems and design new ideas. ISHSs capitalized on the authentic nature of learning by creating in-class and across-class integration of subject matter (Denson, Austin, Hailey, & Householder, 2015). Authentic problem or project based scenarios easily became part of the curriculum because of the premium on integrated subject matter. The curriculum design and instructional implementation reflected this way of learning through authentic, contextualized and interdisciplinary lessons that encouraged collaboration rather than isolation. Certo, Cauley, and Chafin, (2003) found that students were more engaged in an instructional program that included authentic experiences, challenging activities, and worked to build student interest in learning and interpersonal relationships with adults and peers. The schools in this study corroborate this finding.

Teachers used these same 21st Century skills to develop lessons. Teachers worked together on the design of lessons, and sometimes on the implementation of lessons, regardless of disciplinary background, which further demonstrated the value they placed on interdisciplinary, collaborative problem solving (Breiner et al., 2012; Johnson, 2013). Bidwell and Yasumoto (1999) found a similar phenomenon in their study on faculty organizational control, finding three themes: (a) faculty social organization provided structural and normative capacity for control of instruction, (b) local cultures of practice emerged, and (c) focus in each subject depended on the strength of the norms of practice in each field.

Finally, the schools were small and nimble, using flexible scheduling strategies and multiple sources of data to hone in on student and school needs (Ford, 2017). The ISHSs had systematic ways of collecting data on student progress using a variety of sources to build a full picture of the student and could provide informed, individualized learning for their students. Similarly, Cooper, Ponder, Merritt, and Matthews (2005) found that data-directed dialogue and collaborative instruction was a factor in high performance on state assessments for high schools. The data collection and analysis techniques at the eight schools in this study were key in supporting students who had not yet met standards for the rigorous learning expectations.

Emerging from these similarities, a model of inclusive STEM high schools was constructed as portrayed in Figure 1. Students experienced STEM learning opportunities through both classroom activities and strategies (including mastery learning, and relying on non-traditional content sources) and through school level opportunities and features (including group projects and summative projects, as well as interdisciplinary courses or projects). These learning opportunities both shaped and were shaped by school-wide STEM features and approaches (including course scheduling, scheduling students into courses, ensuring engineering or design thinking are accessible, providing real-world connections and 21st Century skill building, and supporting teachers through collaboration). Linking the classroom and school levels together through mutual influence were responsive design systems.

ISSN:2149-8504 (online)

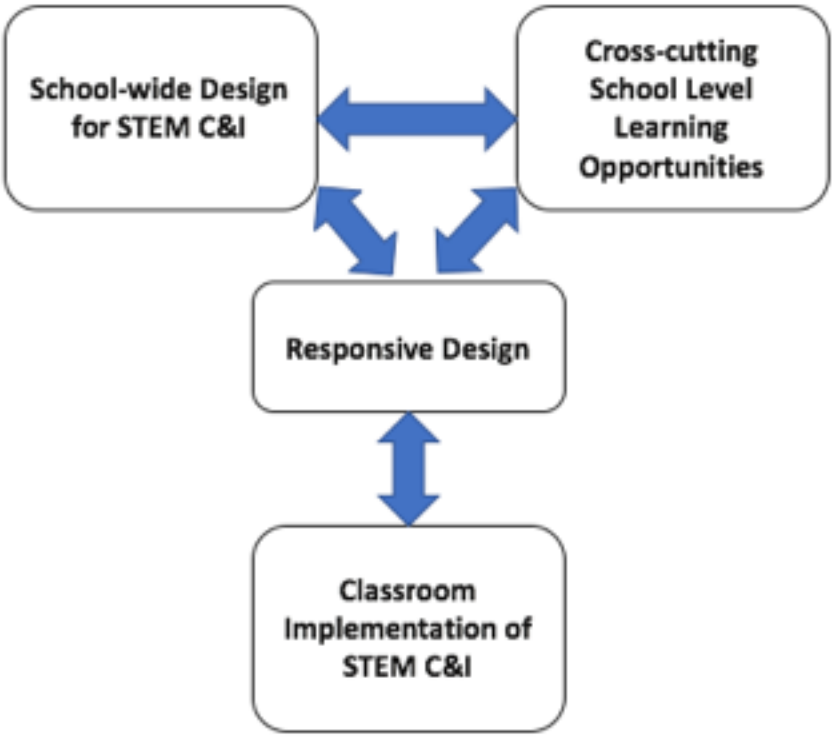

Figure 1. Model of Inclusive STEM High School Curriculum and Instruction

Unique contextual characteristics

All of the schools in this study had devised ways to create opportunities for their students through classroom implementation, cross-cutting school-level learning, school-wide design, and did so in ways that were responsive to the needs and interests of the students and the school community. However, the context in which the school operated and the resources available to the schools differentiated the ways that the schools accomplished these aims. The eight schools in the study had three different categories of what they valued in terms of curriculum and instruction: PBL-focus (Manor and HTH), college credit focus (Wayne, Metro, and DSST), or career focus (CHSAS, DLMHS, and USA). Some schools, such as Manor and HTH, wanted their students to have extensive problem-solving skills and focused their efforts toward student production. Whereas other schools, such as Wayne, Metro and DSST, focused their efforts toward early college credits for their students. The last group of schools, CHSAS, DLMHS and USA, were focused on providing opportunities for students to experience skill and knowledge building through the context of career development (van Breukelen, D., Smeets, M., & de Vries, M., 2015). To a certain extent, these choices directed the partnerships the schools built (Watters & Diezmann, 2013). For example, HTH leveraged extensive community support and strong partnerships with industry professionals and businesses locally. Therefore, authentic PBL learning coupled with collaboration with partners and assessment of student work by professionals was a natural fit to create more STEM opportunities. Wayne and Metro were designed to include local institutions of higher education, thus partnering to offer early college credit for students was their way of developing STEM opportunities. CHSAS designed curriculum for students to gain basic academic knowledge for the first two years of high school and then transition to an entirely integrated pathway that focused on career development. The schools were thoughtful about how they built STEM curriculum and instruction given their context and their local resources, devising their own ways of offering intensive and rigorous STEM in preparation for students' future success.

ISSN:2149-8504 (online)

Implications

National organizations including PCAST (2010a; 2010b) and the National Research Council (2011) have called for more research all types of STEM schools: selective, inclusive, and career technical. The results of this cross-case analysis contribute to much needed literature on the curriculum and instruction in STEM schools with strong outcomes, thus contributing to a baseline for further study and delivering insights to policy makers regarding designing and supporting STEM education (Breiner et al., 2012; Johnson, 2013). School staff wishing to increase their STEM offerings or build a STEM-focused school can look to the variety of ways that the exemplar schools created opportunities for their students based on their own contexts. One of the aims of the study was to document ISHSs from a wide variety of school environments in order to provide relatable school environments for other schools wishing to increase their STEM curriculum and instruction focus. School staff can use the four categories of STEM-focused activities from this study to organize their efforts in classroom implementation, cross-class curriculum design, school-wide design, and responsive design in their own schools. Although each of the exemplar schools in this study invented their own way of addressing STEM curriculum design and instructional implementation, there were common factors to the design and implementation of the curriculum and instruction which can guide other schools.

Beyond viewing this rich set of practices and design features as separate elements for adoption and adaptation, the findings of this analysis also demonstrate that these eight exemplar settings for inclusive and effective STEM education bring the identified components together into a school model (Figure 1). The curricular and instructional elements identified in this study were, nearly always, significant aspects of each of the eight school designs. Certainly a single teacher or a single department can incorporate some of the features examined in this analysis. Yet the school level and cross cutting features were also important aspects of the curriculum and instruction of these exemplar schools (Eleftheria, Sotiriou, & Doran, 2016) and likely were crucial to the high rates of student success (see Author & Colleagues, 2017 for more detailed explanation of student outcomes for the eight ISHSs). The combination of these features at both the classroom and school-wide level, then, provides a synergistic result, noteworthy for those wanting to better understand and emulate the success of highly effective inclusive STEM high schools.

The most significant limitation of this study is it contains only eight schools within its analysis. It also focuses on a specific type of high school, rather than being able to speak about the larger field of secondary education. Yet the detail and rigor of the eight cases analyzed, and their established success providing secondary STEM education for students underrepresented in STEM fields offers a unique set of insights into effective STEM curricular and instructional strategies.

References

Atkinson, R. D., Hugo, J., Lundgren, D., Shapiro, M. J. & Thomas, J. (2007). *Addressing the STEM challenge by expanding specialty math and science high schools*. Washington, DC: National High School Center. Retrieved from http://www.ncsssmst.org

Colleague & Author. (2008). Bill and Melinda Gates Report.

Peters-Burton, E. E., Behrend, T., Lynch, S. J. & Means, B. (2014). Inclusive STEM high school design: Ten critical components. *Theory into Practice*, *53*, 1-8 .

Author and Colleagues. (2018). Journal of Research in Science Teaching.

Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). Report of the 2012 National Survey of Science and Mathematics Education. Chapel Hill, NC: Horizon Research, Inc.

Bidwell, C. E. & Yasumoto, J. Y. (1999). The collegial focus: Teaching fields, collegial relationships, and instructional practice in American high schools. Sociology of Education, 72(4), 234 – 256.

ISSN:2149-8504 (online)

Breiner, J., Harkness, M., Johnson, C. C., & Koehler, C. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 3–11.

Carroll, M. (2015). Stretch, dream, and do: A 21st Century design thinking & STEM journey. *Journal of Research in STEM Education*, *1*(1), 59-70.

Certo, J. L., Cauley, K. M., & Chafin, C. (2003). Students' perspectives on their high school experience. *Adolescence*, *38*(152), 705 – 725.

Chung, C. J., Cartwright, C., & Cole, M. (2014). Assessing the impact of an autonomous robotics competition for STEM education. *Journal of STEM Education*, *15*(2), 24-34.

Corcoran, T. & Silander, M. (2009). Instruction in high schools: The evidence and the challenge. *The Future of Children*, *19*(1), 157-183.

Cooper, J. E., Ponder, G., Merritt, S., & Matthews, C. (2005). High-performing high schools: Patterns of success. *National Association of Secondary School Principals*, *89*(645), 2–24.

Cotabish, A., Dailey, D., Robinson, A., & Hughes, G. (2013). The effects of a STEM intervention on elementary students' science knowledge and skills. *School Science and Mathematics*, *113*(5), 215-226.

Denson, C. D., Austin, C., Hailey, C., & Householder, D. (2015). Benefits of informal learning environments: A focused examination of STEM-based program environments. *Journal of STEM Education*, *16*(1), 11-19.

Eleftheria, T., Sotiriou, S., & Doran, R. (2016). The "Big Ideas of Science" for the school classroom: Promoting interdisciplinary activities and the interconnection of the science subjects taught in primary and secondary education. *Journal of Research in STEM Education*, *2*(2), 72-89.

Elmore, R. (1996). Getting to scale with good educational practice. *Harvard Educational Review*, *66*(1), 1-27.

Eisenhart, M., Weis, L., Allen, C. D., Cippolone, K., Stich, A., & Dominguez, R. (2015). High school opportunities for STEM: Comparing inclusive STEM-focused and comprehensive high schools in two US cities. *Journal of Research in Science Teaching*, *52*(6), 763-789.

Fang, N. (2013). Increasing high school students' interest in STEM education through collaborative brainstorming with yo-yos. *Journal of STEM Education*, *14*(4), 8-14.

Ford, M. (2017). Approaches to school leadership in inclusive STEM high schools: A cross-case analysis (Doctoral dissertation). Retrieved from PQDT Open (AAT 10259145).

Grubbs, M. E., & Deck, A. (2015). The water turbine: An integrative STEM education context. *Technology & Engineering Teacher*, *75*(2), 26-30.

Hamilton, L., Halverson, R., Jackson, S. S., Mandinach, E., Supovitz, J. A., Wayman, J. C., Pickens, C., Martin, E., & Steele, J. L. (2009). Using Student Achievement Data to Support Instructional Decision Making. *United States Department of Education*, Retrieved from http://repository.upenn.edu/gse_pubs/279

Hiller, S. E., & Kitsantas, A. (2014). The effect of a horseshoe crab citizen science program on middle school student science performance and STEM career motivation. *School Science and Mathematics*, *114*(6), 302-311.

Johnson, C. C. (2013). Conceptualizing integrated STEM education. *School Science and Mathematics*, *113*(8), 367-377.

Lamb, R., Akmal, T., & Petrie, K. (2015). Development of a cognition-priming model describing learning in a STEM classroom. *Journal of Research in Science Teaching*, *52*(3), 410-437.

Lamberg, T. & Trzynadlowski, N. (2015). How STEM Academy teachers conceptualize and implement STEM education. *Journal of Research in STEM Education*, *1*(1), 45-58.

Lent, R.W., Brown, S.D., & Hackett, G. (1994). Toward a unifying social cognitive theory of career and academic interest, choice, and performance. *Journal of Vocational Behavior*, *45*(1), 79–122.

ISSN:2149-8504 (online)

Lynch, S. J., Spillane, N., House, A., Peters-Burton, E. E., Behrend, T., Ross, K. M., & Han, E. (2017). A policy-relevant instrumental case study of an inclusive STEM-focused high school: Manor New Tech High. *International Journal of Education in Mathematics, Science and Technology*, *5*(1), 1-20.

Lynch, S. J., Peters-Burton, E. E., Behrend, T., House, A., Ford, M., Spillane, N., Matray, S., Han, E., & Means, B. (2018). Understanding inclusive STEM high schools as opportunity structures for underrepresented students: Critical components. *Journal of Research in Science Teaching*. DOI 10.1002/tea.2143

Mehta, J. & Cohen, D. (2017). Why reform sometimes succeeds: Understanding the conditions that produce reforms that last. *American Educational Research Journal*, *54*(4), 607-643.

Mohr-Schroeder, M. J., Jackson, C., Miller, M., Walcott, B., Little, D. L., Speler, L., Schroeder, D. C. (2014). Developing middle school students' interests in STEM via summer learning experiences: See Blue STEM Camp. *School Science and Mathematics*, *114*(6), 291-301.

Morrison, J., Roth-McDuffie, A., & French, B. (2015). Identifying key components of teaching and learning in a STEM school. *School Science and Mathematics*, *115*(5), 244-255.

Naizer, G. (2014). Narrowing the gender gap: Enduring changes in middle school students' attitude towards math, science, and technology. *Journal of STEM Education*, *15*(3), 29-34.

National Research Council. (2004). *Engaging schools: Fostering high school students' motivation to learn*. Committee on Increasing High School Students' Engagement and Motivation to Learn. Washington, DC: National Academies Press.

National Research Council. (2005). *How students learn: History, mathematics, and science in the classroom*. Committee on How People Learn, A Targeted Report for Teachers. M.S. Donovan and J.D. Bransford (eds.). Washington, DC: National Academies Press.

National Research Council. (2010). *Preparing teachers: Building evidence for sound policy*. Committee on the Study of Teacher Preparation Programs in the United States. Washington, DC: National Academies Press.

National Research Council. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Committee on Highly Successful Science Programs for K-12 Science Education. Board on Science Education and Board on Testing and Assessment, Division of Behavioral and Social Sciences and Education. Washington, D.C.: The National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

NGSS Lead States (NGSS). (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

Oyana, T. J., Garcia, S., Hawthorne, T., Haegele, A., Morgan, J., Young, N. (2015). Nurturing diversity in STEM fields through geography: The past, the present, and the future. *Journal of STEM Education*, *16*(2), 21-29.

President's Council of Advisors on Science and Technology (PCAST). (2010a). *Prepare and inspire: K-12 education in science, technology, engineering, and mathematics (STEM) for America's future*. Washington, DC: Author.

President's Council of Advisors on Science and Technology (PCAST). (2010b). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics*. Washington, DC: Author.

Rahm, J., & Moore, J. C. (2015). A case study of long-term engagement and identity-in-practice: Insights into the STEM pathways of four underrepresented youths. *Journal of Research in Science Teaching, 3*(5) 768-801.

ISSN:2149-8504 (online)

Rennie, L.,Venville,G., & Wallace, J. (2012). *Integrating science ,technology, engineering, and mathematics: Issues, reflections, and ways forward*. New York: Routledge.

Reynolds, D., Yazdani, N. Mazur, T. (2013). STEM high school teaching enhancement through collaborative engineering research on extreme winds. *Journal of STEM Education*, *14*(1), 12-19.

Roehrig, G. H., Moore, T. J., Wang, H. H., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics*, *112*(1), 31–44.

Roberts, K. (1968). The entry into employment: An approach towards a general theory. *Sociological Review*, *16*, 165-184.

Sahin, A. (2013). STEM clubs and science fair competitions: Effects on post-secondary matriculation. *Journal of STEM Education*, *14*(1), 5-11.

Scott, C. E. (2009). *A comparative case study of characteristics of science, technology, engineering, and mathematics (STEM) focused high schools*. Retrieved from Proquest (AAT 3365600).

Spillane, N. K. (2017). *Teacher characteristics and school-based professional development in inclusive stem-focused high schools: A cross-case analysis*. Retrieved from Proquest (AAT 3687663).

Stake, R. E. (2006). *Multiple case study analysis*. New York, NY: The Guilford Press.

Subotnik, R.F., Tai, R. H., Rickoff, R., Almarode, J. (2010). Specialized public high schools for science, mathematics, technology and the STEM pipeline: What do we know now and what will we know in five years? *Roeper Review, 32*, 7-16.

van Breukelen, D., Smeets, M., & de Vries, M. (2015). Explicit teaching and scafolding to enhance concept learning by design challenges. *Journal of Research in STEM Education*, *1*(2), 87-105.

Watters, J. J., & Diezmann, C. M. (2013). Models of community partnerships for fostering student interest and engagement in STEM. *Journal of STEM Education*, *14*(2), 47-55.

Yin, R. K. (2003). *Case study research: Design and methods (3rd ed.)*. Thousand Oaks, CA: Sage Publications, Inc.

ISSN:2149-8504 (online)

Journal of Research in STEM Education

Vol 4, No 2, December 2018, 213-234

RESEARCH REPORT

The Impact of Engagement in STEM Activities on Primary Pre-service Teachers' Conceptualization of STEM and Knowledge of STEM Pedagogy

Mehmet Aydeniz[a1], Kader Bilican[b]

[a]*The University of Tennessee, USA;* [b]*Kırıkkale University, TURKEY*

Abstract: *The purpose of current study was to explore the weaknesses and strengths in pre-service primary teachers' (PST) conceptualization of STEM and their knowledge of STEM pedagogy after engaging in integrated STEM (science, technology, mathematics and engineering) activities for one semester. The course activities emphasized concepts related to engineering design process, the interrelatedness of STEM subjects, inquiry and problem solving. The integrated STEM activities were implemented for six weeks. Data were collected through a questionnaire, reflection papers, semi-structured interviews with a sub set of participants (n=8/20). Results show that engaging students in immersive STEM activities helped PSTs develop foundational knowledge regarding STEM, engineering design and STEM pedagogy, which they could built on later to more effectively teach through STEM integration. Discussion focuses on how PSTs and practicing teachers can be supported through sustained professional development for STEM integration pedagogy.*

Keywords: Engineering, science, pre-service teachers, professional development, STEM

Introduction

STEM education has dominated the educational reform discourse in the last few years all over the developed and developing countries. As a result, public schools from pre-K to high schools have adopted the demand of this discourse and looking for ways to teach STEM subjects through an integrated approach. While the demand to teach STEM subjects through an integrated fashion across k-12 education has intensified, case studies from classrooms suggest that teachers have limited understanding of integrated STEM and STEM pedagogy (Honey, Pearson, & Schweingruber, 2014). More, when they attempt to teach science through integration, they face unique difficulties. These observations have motivated science educators to investigate and characterize teachers' conceptions of STEM, and the unique challenges teachers face when teaching through integration. In this study, we report findings of a study in which we attempted to improve pre-service primary school teachers' conceptual understanding of STEM integration and their pedagogical knowledge of STEM though immersive STEM integration activities. The research question we pursued was:

- What are the weaknesses and strengths associated primary teachers' conceptions of STEM integration and STEM pedagogy after engaging in integrated STEM activities for one semester?

[1] Corresponding author. A 408 Jane & David Bailey Education Complex 1126 Volunteer Blvd, Knoxville, TN 37996-3442, Email: maydeniz@utk.edu

Aydeniz, M., & Bilican, K. (2018). The Impact of Engagement in STEM Activities on Primary Pre-service Teachers' Conceptualization of STEM and Knowledge of STEM Pedagogy. *Journal of Research in STEM Education*, *4*(2), 213-234

ISSN:2149-8504 (online)

Significance of the Study

While there are several studies that focus on teachers' conceptions of STEM integration and their pedagogical knowledge of STEM. Most STEM integration studies in the current literature related to teacher learning have been conducted in the United States (Guzey et al, 2016; Honey, Pearson, & Schweingruber, 2014; Kim and Bolger, 2017; Wang, Moore, Roehrig, & Park, 2011). Moreover, even then sufficient effort has not been devoted to primary science teachers' conceptions and pedagogical knowledge of STEM integration. However, research studies show that students start to develop conceptions about STEM at young ages. Considering the importance of early experiences on students' conceptions and identities related to STEM (McCoach et al., 2006; Sullivan, 2016; Tippet & Milford, 2017), primary teachers' conceptions of STEM and pedagogical knowledge of STEM merits attention and further inquiry.

Review of Relevant Literature

Conceptualization of STEM

The term STEM has been used widely among education, industrial and policy communities. Policy makers and industry leaders use STEM to emphasize the importance of a population that is educated in any of the STEM fields. In educational context, however, the term STEM refers to the teaching of STEM subjects in an integrated fashion. This can happen in different combinations. For some, integration of engineering design and technology is sufficient for an activity or curriculum to be called STEM, for others, it refers to the inclusion of all four STEM subjects in the curriculum or a specific lesson. Mobley (2015) defines Integrated STEM as:

> An approach to teaching and learning in which any combination of the four major STEM disciplines is taught in a manner such that the curriculum and content of the individual disciplines seamlessly merge into real-world experiences contextually consistent with authentic problems and applications in STEM careers. Such integration includes close and intentional attention to the inclusion of core disciplinary practices of each STEM domain being integrated, and purposeful attempt to make meaningful connections between the core concepts of each discipline, with the goal of using this integrated knowledge to solve real-world problems (p.14).

Sanders (2008) argue that integrated STEM learning experiences must include technological and engineering design as a basis for making connections between concepts and practices of science and mathematics. While there is no consensus on what STEM means, integration of more than one subject, active engagement of students in authentic, design-based learning tasks, reasoning through sustained inquiry and application of STEM knowledge and skills in real-world contexts to solve a problem, through student-centered, constructivist and collaborative pedagogies is key to STEM integration. However, rarely has the focus on problem solving and inquiry has been made explicit in our discourse. More often, it is not the problem solving and inquiry that gets discussed but the inclusion of engineering and the integration of STEM subjects.

Review of Studies on STEM Pedagogy

Since its popularization in 2000s several STEM educators have conducted studies related to integrated STEM education (Cervetti, Barber, Dorph, Pearson, & Goldschmidt, 2012; Guzey et al., 2016; Harwell, Philips, Mareno, Guzey, Moore, 2015; Lam, Alviar-Martin, Adler & Sim, 2013; Lederman & Lederman, 2013; Roehrig, Moore, Wang & Park, 2012). While some studies have attempted to explore the potential benefits of integrated STEM for students' learning outcomes (Childress, 1996; Guzey et al., 2016; Riskowski, Todd, Wee, Dark & Harbor, 2009)), others have focused on the challenges faced by STEM teachers to teach science through an integrated framework (Lam et al, 2013; Lehman, Kim, & Harris, 2014) Studies that focus on learning outcomes, maintain that learning science through an integrated fashion improves students' problem solving skills, their critical thinking skills, collaboration skills and results in better conceptual understanding. However, whether

ISSN:2149-8504 (online)

these reported benefits are significantly different from learning science through a single subject approach or not begs further empirical support.

While many benefits of STEM integration have been advocated, teachers struggle to buy into the idea of teaching through an integrated fashion. Further, even when they are convinced of the value of integration, they have limited experiences with learning through STEM integration or lack pedagogical knowledge to teach through integration (Ring et al., 2017). The fundamental challenges associated with teaching through an integrated fashion include: teachers' resistance to teach through an integrated fashion (attitudinal) because of lack of or limited experiences (Frykholm & Glasson, 2005; Gresnigt, Taconis, van Keulen, Gravemeijer & Baartman, 2014), teachers' belief that teaching through integrated fashion compromises students' conceptual understanding of core subject content (Estapa &Tan, 2017), lack of resources to teach through an integrated fashion, teachers' lack of knowledge and experiences in engineering and technology, and lack of time for shared planning (Lederman & Lederman, 2013; Yeung &Lam, 2007). Collectively, these studies suggest that: 1) teachers hold naïve conceptions related to STEM integration, 2) teachers do not hold adequate pedagogical knowledge and skills to teach through STEM integration, and 3) consequently, teachers are not well prepared to implement integrated STEM curriculum in their classrooms. If this is the case, then teacher educators should assume the responsibility to make a difference in teachers' conceptions of STEM and promote their students' acquisition of pedagogical knowledge related to STEM integration through effective interventions. The first step in accomplishing this goal would be to measure PST's conceptions of STEM, and their pedagogical knowledge related to STEM integration. Such an approach will help us identify problematic areas related to pre-service teachers' conceptions of STEM and their pedagogical knowledge related to STEM integration and address them before they enter the classroom.

Review of Empirical Studies on Student Learning in STEM

STEM integration is believed to increase student motivation, engagement, learning and interest to pursue STEM careers (Moore, 2008). Proponents of STEM integration argue, these utcomes are possible because STEM integration engages students in solution to real-world problems, in a culturally relevant way by requiring them to draw from content knowledge and practices across from different disciplines (Moore, 2008). Since its popularization as a pedagogical approach to teaching science and mathematics, several scholars have explored impact of STEM on student learning, engagement and attitudes, however, not all of these studies report a significantly positive impact rsulting from students' participation in integrated STEM activities.

Wendell and Rogers (2013) conducted a study with middle school students and reported differential effects of integrated STEM on student learning. They exposed students to two different integrated STEM activities. In the first activity, students completed a LEGO-based engineering unit on sound, and in the second activity students completed a LEGO-based engineering unit on simple machines. Interestingly, they found that the students who completed the engineering unit on simple machines developed statistically significant and greater learning gains than those who learned science business as usual. However, authors did not observe the same positive effects on student learning for the sound unit. This suggest that the context in which integration takes place influences the effectiveness of integrated curriculum on student learning. This finding is consistent with other studies that emphasize the importance of context on reported learning outcomes in educational studies (Bennet &Holman, 2002; Trigwell & Prosser, 1991).

LaChapelle et al. (2011) measured the impact of engineering design on students' conceptual understanding. The treatment group in their study completed a unit on organisms through engineering. The control group on the other hand completed a unit only on organisms. They found that the engineering unit did not produce statistically significant impacts on student learning as measured through a post-science content test. More recently, Guzey, Moore, Harwell & Moreno (2016) explored the effects of an engineering unit on middle school students' conceptual understanding and attitudes in three life science classrooms. Three middle school science teachers and 275 seventh grade students participated in the study. Students were engaged in design-based STEM activities for over 15 class of 50 minutes each. The teachers who taught the courses had gone through a rigorous professional development program that consisted of three-week long summer workshops and ongoing professional development throughout school year. The teachers implemented a unit that they had collectively developed during the summer professional development. The authors measured the impact of these activities on students conceptual understanding of science and mathematics. They found that the integrated STEM curriculum did not have a statistically significant effect on students' learning in the domains of science and mathematics.

As the results of these studies indicate, despite lack of consistent and rigorous evidence for effectiveness of STEM integration on student learning, school districts continue to push for integrated STEM curriculum. This demand from schools creates significant need for teachers to develop pedagogical knowledge and skills to teach science through STEM integration. Yet, only few pre-service science teacher education programs across the world are making STEM integration as part of their curriculum. We provide a review of some of these interventions and the impacts they have had on teachers' conceptions and pedagogical knowledge related to engineering.

Review of Empirical Studies on Teaching through STEM Integration

Kim and Bolger (2017) investigated the impact of lesson planning on pre-service teachers' confidence in teaching through STEAM. The participants of this study were 119 pre-service elementary teachers. After exposing the participants to the theory behind STEAM framework and STEAM-based teaching and learning through a two-hour lecture, researchers guided participants to develop a STEAM lesson plan for the subsequent five weeks. After the participants developed their initial lessons, they exchanged lessons and received feedback from each other in class. The students kept working on their lesson plans for the rest of the class and received feedback from their instructor. Finally, they presented their lessons to their classmates through microteaching at the conclusion of the class, the authors found that the act of lesson planning, revision and presentations resulted in increased "awareness, perceived ability, value, and commitment for STEAM" among participants (p. 600). More important, the PSTs thought that an integrated STEAM curriculum would "foster high-level thinking among their future students." (p. 602). Despite these reported positive effects, the authors also found that pre-service teachers experienced significant challenge to develop STEAM lessons. More specifically, they found that PSTs found it difficult to make connections between different components of STEAM. The authors attribute this difficulty to PST's lack of experiences in "looking across subjects to integrate ideas" (p.602). As a result, "they needed guidance to ensure that integrated topics were all addressing learning objectives at the appropriate grade level" (p. 602). This observation is important and point to the complexity of enternatining multiple goals related to content, practice, and skills when planning and teaching integrated STEM lessons.

In a recent study conducted with PSTs in the United States, Estapa and Tank (2017) found that when PSTs received support from engineering graduate students, they were able to come up with a "large number and variety of engineering concepts" that could be connected to the target design activity. The authors analyzed lesson plans designed by each of the 10 triads and found that only few lessons explicitly made references to science or math content goals. More, when the authors observed their lessons in action they observed that "the content learning focused mostly on engineering design and skills or practices, such as teamwork" rather than science and math content. Clearly, this is a problem for elementary STEM teachers. While design-based activities help students acquire invaluable engineering design skills, without explicit attention to content standards, STEM integration cannot result in intended outcomes.

Stohlmann et al. (2012) studied four middle school teachers' implementation of an integrated STEM curriculum. While they report that, "The teachers were not focused on lecturing, but on having students work together and develop their own ideas, they had difficulties knowing how long lessons would last and knowing how to best guide students in their work" (p. 31). They emphasize several areas of concern expressed by four teachers teaching in an integrated STEM framework in the study. The first observation was teachers' obsession with controlling the learning environment. They found that because integrated STEM teaching priorities student ownership and autonomy over learning goals, activities and outcomes, teachers become nervous

ISSN:2149-8504 (online)

about the content and process of learning. Second, they found that provision of sufficient resources necessary for students to pursue their induvial projects (i.e., to design, test, and revise solutions to problems) becomes problematic (Stohlmann et al., 2012, p. 30). The topic of necessary resources to teach through integrated STEM has been reported in other studies as well. These studies emphasize that teachers' confidence in their ability to implement integrated lesson plans were directly associated with availability of relevant and ready to use curricular materials (Guzey, Nyachwaya, Moore, & Roehrig, 2014; Mobley, 2015) and time to develop and teach lessons. For instance, Mobley (2015) found that teachers were concerned about time to collaborate with other STEM teachers to design lessons, lack of classroom time to implement integrated STEM lessons with maximum fidelity and support for learning about ways to teach integrated STEM lessons in an effective manner.

Collectively, these studies suggest that teachers need a special type of pedagogical knowledge, time and resources for planning and teaching integrated STEM lessons. However, we do not know precisely what this type of knowledge might look like, and how to go about helping STEM teachers to develop such knowledge and skills to teach STEM lessons with limited resources and within the confines of traditional school bell schedule. This is especially true for novice teachers who enter the classroom with the expectations and demands related to STEM integration. Therefore, engaging preservice teachers in immersive activities in which they are given the opportunity to question, reflect on and discuss their conceptualization of STEM, as well as experience STEM –based learning activities and collaboratively design lessons through an integrated framework becomes very important. These experiences can help them become aware of the problems with their conceptualizations of STEM, the challenges associated with designing STEM-based lessons, and plan accordingly. In this study, we explore these issues through a qualitative approach. The driving question for this study is:

- What are the weaknesses and strengths associated primary teachers' conceptions of STEM integration and STEM pedagogy after engaging in integrated STEM activities for one semester?

Methodology

Consistent with the exploratory nature of this study, we adopted a qualitative approach for studying PST's experiences with immersive STEM activities. Our approach is rooted in the Interpretivist epistemology, which aims to interpret human experiences and interactions within the relevant context (Crotty, 1998). Interpretivist approaches rely on contextually revelatory methods such as interviews, and content analyses of relevant documents and observations (Guba & Lincoln, 1994). This approach is suitable for this study because, we are interested in exploring issues with PST's conceptualization of STEM, and problems with their pedagogical knowledge related to STEM education.

Participants

Participants of the study were 20 (17 females, 3 males) sophomore primary pre-service teachers (PST). All of the participants were attending their third semester at a primary science education program in Turkey. The study took place in the first science laboratory course that these participants took as part of their program. Most of them had rarely engaged in inquiry-based science learning or had taken any inquiry-based science courses either at college or during their k-12 educational experiences prior to taking this course. Most of their science learning experiences were limited to teacher-centered instruction and not any experiences related to STEM integration. Within the primary teacher education program, they took general science courses such as introduction to physics, chemistry and biology in their first three semesters of their program from content experts. They took the science laboratory course, the context of this study, at the third semester of the primary teacher education program. The class was heavily focused on application of science process skills in conducting inquiry based experiments. The course's overall goal was to provide students with first hand-on experiences about basic concepts of chemistry, biology and physics through inquiry-based methods.

ISSN:2149-8504 (online)

Intervention

The intervention started at the sixth week of the science laboratory course mentioned aboive. The participants were engaged in inquiry based laboratory activities during the first 6 weeks of the class. The rest of the class was devoted to helping pre-service teachers to understand and experience the concept of integrated STEM and pedagogical approaches implemented in integrated STEM contexts. First, we introduced the participants to the field of engineering through expert visits to the class and engaged participants in some basic engineering activities introduced by the epxerts (i.e., engineering faculty). Then, pre-service teachers were engaged in STEM tasks to realize and practice teaching of science content in an integrated way by using engineering design processes.

The intervention started with a visit of a faculty member from mechanical engineering department of the same university. The faculty member's talk focused on engineering practices in the context of mechanical engineering and how engineers think about problems and design solutions. The second author, also the instructor of the course intervened as the context demanded, and attempted to help students connect the points highlighted by the guest speaker to engineering design processes explicitly. Then, pre-service primary teachers visited a mechanical engineering laboratory, to get a concrete picture of the types of research that mechanical engineers do. They asked questions and received answers related to nature of the work of mechanical engineers.

At the second week, another colleague from computer engineering department visited the class and gave a talk about what computer engineers do, how they think and approach solutions to the problems that interest them.The main aim of these visits from other engineering departments was to familiarize participants with engineering practices, and help them conceptualize engineering design process. At the end of his lecture, he conducted a coding activity with the participants. He walked the students through a basic coding activity using phyton (a programming language).

At the end of these visits, participants were required to reflect on and write down how these visits contributed to their understanding of engineering practices, and their understanding of the relationships between different components of S-T-E-M. They were also required to make connections between ideas discussed during the guest lectures and teaching STEM in an integrated manner, with an explicit focus on engineering design. After the students were introduced to the concepts of engineering, they participated in three integrated STEM activities. Each task was accompanied by some guiding questions drawing students' attention to the S-T-E-M components and specifically engineering design. The guiding questions that pre-service teachers were required to think about were; "what is the science content in the task?", " how is this task related to math, where is the technology and engineering design in this activity?", and "when and how did you use engineering design in this task?"

The first activity that the students engaged in was the egg drop challenge. The activity took two weeks. Participants worked in groups, in the first week they decided on their proposed design solution to the problem and the design of their prototype. The following week, each group tested their design in class, then each group discussed the success and failure of their designs in their groups. After, testing of the prototypes, the students were guided to discuss the pedagogical issues related to the implementation of this STEM activity in their future classrooms. First, participants were encouraged to discuss how this STEM activity differed from a regular inquiry-based laboratory activity. Then, the researcher highlighted the engineering design processes that participants experienced while completing the task. Participants were expected and guided to discuss the engineering design component in the tasks they engaged in and desigend. Finally, participants were asked to connect related activity with science curriculum that they are expected to teach after graduation.

The participants were then provided with the second STEM activity called twirly activity (Savran & Gencer, 2015). The activity aimed to differentiate science and engineering practices by providing a context in which participants conducted a scientific investigation. At the end of the task, participants filled an activity worksheet which included such questions as how the activity is related science and mathematics, how their prototype worked and what features of the scientific investigation they participated in while competing the learning task. The course instructor facilitated an intergroup discussion about the content of their group work and discussions. During week five, participants engaged in the "baking soda and vinegar powered car" STEM activity (https://sciencing.com/make-car-baking-soda-vinegar-6498045.html). The professor posted a question related to constructing a car that worked without gas the week before this activity. Then, participants were asked to come up with design ideas regarding construction of a car that worked without fossil fuels. The participants tested their ideas and made a final design of their prototype in the following week. Similarly, after the activity, the professor facilitated a class discussion about the engineering design processes that they used while completing this activity and asked them to reflect on connections to teaching integrated STEM lessons. Moreover, the participants were required to fill in the activity sheet in which discussion questions were provided and participants were required to respond individually. During week six, participants were asked to design a STEM lesson as a capstone assignment for the course. Participants could choose any science content but were required to connect the designed activity to the Turkish National Science Standards. In addition, they were asked to explicate how the task reflected engineering design processes. The summary of our intervention is provided in Table 1.

Table 1.
Summary of Intervention

WEEK	Activity	Purpose	Nature of the Activity	Length
WEEK 1	Mechanical Engineering Faculty Visit/ Visit to laboratories of Mechanical Engineering Department	To help students understand the work of engineers. To help students gain perspective on the types of problems mechanical engineers work on and the ways in which they go about designing solutions. To help students understand the engineering design processes.	Lecture/guided tour of the lab. Questions&Answers Reflection on the experience.	3 Hours
WEEK 2	Computer Engineering Faculty visit / Coding activity	To help students understand the work of engineers. To help students gain perspective on the types of problems computer engineers work on and the ways in which they go about designing solutions.	Lecture/ Guided hands-on coding activity. Questions/Self reflection	3 hours
WEEK2 & WEEK3	Egg drop challenge Twirly Activity	To engage in problem solving. To differentiate science and engineering practices. To think about the integrated nature of science, math and engineering.	Student initiated / inquiry based engineering design activity	2weeks/ 6 hours
WEEK 4	Baking soda and vinegar powered car	To experience engineering design processes To engage in inquiry-based learning To engage in problem solving. To understand the connections between STEM content and practices.	Student iniated/ inquiry based engineering design activity	1Week /3 hours

ISSN:2149-8504 (online)

WEEK 5 & WEEK6	Preparation and presentation of integrated STEM activity	To see if the students can design integrated STEM-based learning activities.	Student iniated/, inquiry based, engineering design activity	2Week / 6 hours

Data and Data Collection

Data were collected through qualitative data collection methods. Data consisted of participants' responses to an open-ended questionnaire, post interviews, and written reflection papers after guest lectures. All participants were asked to answer questions on the open-ended questionnaire (see Appendix A) regarding their conceptualizations of STEM, STEM pedagogy, engineering design, pedagogy of engineering design, and challenges related to teaching STEM through an integrated manner. While we administered the questionnaire both before and at the conclusion of intervention, we primarily relied on the post-intervention responses, because participants held very naïve conceptions, gave very short responses and could not elaborate on their responses on the pre-test.

In addition to the open-ended questionnaire, we conducted post interviews with eight participants who volunteered to be interviewed. These interviews were audio –recorded. The interviews were semi-structured and participants were asked to elaborate on their responses given in the questionnaire. The purpose of these interviews was to get an in-depth understanding of participants' conceptualization of STEM, STEM pedagogy, engineering design process and pedagogy of integrating engineering design into their STEM lessons.

Data Analysis

We primarily relied on content analysis methods in analyzing our data. Data analysis consisted of content analysis of PSTs' responses to the open-ended STEM integration survey, interview transcripts and reflection papers. Content analysis methods requires systematically analyzing evidentiary materials and reduce findings to pre-conceived categories to describe the phenomenon (Mostyn, 1980).

In our analyses, we did not focus on comparison of pre- and post-questionnaire responses, rather we only focused on analyzing PSTs' post-questionnaire responses, reflection papers and the results of interviews with a subset of PSTs (n=8). This method was adopted because instead of focusing on the effectiveness of our intervention, we were most interested in identifying the weaknesses and strengths in PSTs conceptions and knowledge related to STEM integration after we provided them relevant integrated STEM experiences. This approach we think offers valuable insight about the needs of PSTs related to STEM integration because participants held naïve conceptions about what integrated STEM meant at the beginning. They made an attempt to conceptualize what integrated STEM might mean at the beginning but heir initial conceptualizations focused only on the integration of math and science, and some participants left the answer sections blank. So, the quality of evidence provided on the pre-test questionnaire was very low and did not allow for meaningful comparision of pre and post.

We defined preliminary broad coding themes based on the purpose of our study, and the questions we had asked of the participants in our questionnaire, interviews and reflection papers. These initial categories were further solidified, modified or refined through triangulation across different data sources (Miles & Huberman, 1994). While most themes were dictated by our questionnaire and interview questions, we continually revisited, refuted, revised, modified and added new themes as our analysis across different data sources progressed. Through this iterative process, common and consistent themes emerged across our data. These themes include: STEM conceptualization and justification, STEM pedagogy, perceived benefits of teaching through integrated stem, conceptions of teaching through engineering design, justifications for teaching through engineering, challenges experienced while designing integrated STEM, resources needed to teach integrated STEM.

ISSN:2149-8504 (online)

The data analysis was conducted by the two authors and involved several steps. First, each author independently read participants' responses to the questionnaire, and content of participants' responses to the interview questions. Our goal in this stage was to categorize participant's responses to the pre-determined themes, add additional themes if emerged from the data, and make sense of students' responses. Second, the authors met to discuss their categorization of the themes, and address differences in their interpretations of participants' responses and come to a consensus about the categories and perceived meaning of participants' responses. Finally, participants' responses were categorized as being relatively more sophisticated to relatively less sophisticated. For instance, sophistication of participants' answers related to STEM was determined based on the intentional integration, focus on engineering design, problem solving, creativity and elaboration on their reasoning for this category.

Results

We present results in the following order: participants' conceptualization of STEM, knowledge of STEM pedagogy, perceived benefits of teaching through STEM integration, conceptions of teaching through engineering design, justifications for teaching through engineering design, participants' understanding of pedagogical demands of STEM integration and resources needed for teaching science through STEM integration. The results of our analyses are reported in the following sections.

Participants' Conceptualization of STEM

The results of our analyses indicate that participants' provided informed answers related to their conceptualization of STEM. Not only did the participants provided elaborate answers but they also made references to creativity, problem solving, design-based solutions and intentional integration of concepts. Despite such an improvement, the sophistication level of participants' conceptualization of STEM varied from one participant to the other participant.

Table 2.
Definitions and Justification of STEM Integration

	Themes	Frequency
STEM Definition & justification	Integration of subjects	17
	Intentional integration of subjects	16
	Problem solving through design	16
	It makes problem solving easier	17
	This how scientists/engineers work in real life/lab situations.	15
	Preparing students for 21st century economy	17

We provide exemplary answers below. One participant defined STEM as:

STEM refers to the intentional effort to integrate and teach math and science concepts through engineering and technology in the classroom. STEM is often taught through integration and hands on activities, and problem-based scenarios. STEM concepts should be taught through integration because all of these fields are connected. Engineering is problem solving through design, mathematics is doing calculations and science is about inquiry. I said engineering is about problem solving. An electrical engineer has to use math and science to develop better solutions to the problems at hand. To solve problems, engineers need to brainstorm and they need to think hard, they need to think creatively, but they also need to use concepts and laws from science, from physics and use math to develop solutions.

ISSN:2149-8504 (online)

This statement shows the sophistication level of this PST regarding STEM integration. The answer highlights the need for integration of concepts and practices of different fields in solving everyday problems through inquiry.

STEM Pedagogy

In an effort to understand the weaknesses and strengths in participants' conceptions of STEM pedagogy, we explored participants' conceptions of STEM pedagogy. Surprisingly, most participants provided answers that aligned well with the accepted reform-based practices in STEM education. However, participants struggled with elaborating on details of the strategies they offered or how they may scaffold instruction for maximum student engagement, productivity and learning. The majority of participants made references to the problem-based nature of STEM learning, emphasized the importance of engineering design in the learning activities proposed, the inquiry nature of learning, the hands-on nature of STEM activities, helping students to make connections across different STEM fields, and the importance of creating a motivational context for students to engage in problem solving.

Table 3.
Participants' Conceptualizations of STEM Pedagogy

	Themes	Frequency
STEM Pedagogy	Problem-based instruction	17
	Project based instruction	9
	Design-based instruction	15
	Creating a context for students to problem solve	12
	Promoting inquiry	16
	Hands-on activity	15
	Giving students opportunity to make connections between STEM fields	17
	Giving students opportunity to integrate knowledge for solving problems	16

The following exemplary statements show both the strength and weaknesses in PST's conceptualization of integrated STEM pedagogy. One participant provided the following answer regarding her conception of STEM pedagogy. He said:

> We need to teach STEM through hands-on activities, and inquiry-based learning. We need to provide the learning environment and context for students to first explore, and problem solve. The focus of instruction should not be transmission of information to the students from the teacher lecture, it should be about encouraging student inquiry and problem solving. Students will themselves establish the relationships and make connections between the science, chemistry and physics concepts and physics and math concepts when attempting to solve a problem or design a solution. We just need to be able to design rich learning activities for them and support them as they design their solutions. Students learn concepts from physics, from chemistry and math independently but when we engage them in integrated STEM activities, we give them the opportunity not only to make connections between concepts, but also it gives us the opportunity to assess their knowledge of each field together.

This exemplary statement shows that the PST focuses on inquiry-based learning, helping students make connections, design and problem solving. These aspects of instruction are aligned with the type of pedagogical practices associated with STEM integration.

ISSN:2149-8504 (online)

Perceived Benefits of Teaching through STEM integration

One of the factors that may play a critical role in mitigating teachers' ability to teach through STEM integration is their views about the perceived benefits of STEM integration. Participants reported several advantages of teaching through integrated STEM. These perceived advantages are reported in Table 4.

Table 4.
Participants' Conceptualizations of STEM Pedagogy

	Themes	Frequency
Benefits of teaching through STEM	Opportunity to assess students' knowledge across different subjects	9
	Helping students to develop problem solving skills	17
	Fosters student curiosity	15
	Fosters student creativity	15
	Help students develop interest in STEM fields	17

The perceived benefits reported by PSTs ranged from giving the teacher the opportunity to assess students' knowledge and skills across different STEM subjects to fostering students' curiosity, students' creativity to helping them to develop problem solving skills. One participant said:

> STEM integration allows the teachers the opportunity to see if the students can transfer and use the knowledge gained from lessons that are taught independently. It encourages the students to develop problem solving skills. It will also foster student creativity and independent thinking because students are faced with a problem case and they are being asked to solve the problem.

As this exemplary statement shows, PSTs were able to see the pedagogical benefits of STEM integration both for teachers and the students. However, most of the PSTs focused on pedagogical benefits of STEM integration for the students.

PST's Conceptions of Teaching through Engineering Design

Since engineering design is central to STEM integration, we wanted to explore PST's conceptions of teaching through engineering design. The results show that PSTs were able to elaborate on various aspects associated with teaching through engineering design. The themes emerged from participants' answers are provided in Table 5.

ISSN:2149-8504 (online)

Table 5.
Participants' Conceptualizations of Teaching through Engineering Design

	Themes	Frequency
Conception of teaching through engineering	Creating a context for students to ask questions	12
	Promoting design-based thinking	15
	Engaging students in problem solving	17
	Encouraging student creativity	12
	Providing opportunity to test ideas, design solutions.	16
	Coming up with alternative solutions	14
	Making observations to determine a problem	13
	Systems thinking	9
	Figuring things out	17
	Making calculations	11
	Varying variables to make the system work efficiently or to fit the model.	13
	Testing: Trial and failure.	16
	Brainstorming	15
	Questioning	13

These results show that PSTs started to build a foundational understanding for teaching STEM through engineering design. We provide exemplary statements provided by one PST regarding her understanding of engineering practices, the engineering nature of her lesson, along with her justification as to why she thinks her lesson is an engineering design-based lesson in Table 6.

Table 6.
Exemplary Answer for Understanding of the Engineering Nature of the Lesson and Justification

Aspect	Participant's Answer
Engineering Practices	When I think of engineering practices, design thinking, evaluation, testing, making predictions, making observations, and looking at things from different perspectives, alternative solutions, come to my mind. When a student looks at a cooler, he /she they only see a cup made up of aluminum but when they look at its function they see engineering design. Students then think of all engineering practices and design thinking that has been used by engineers in designing the cooler. They start to think and ask, What materials we must use?, How we must use these materials? What design should be use and why? During the engineering design process, you must identify a problem, develop a tentative solution, test the solution to see if it serves the function, evaluate the results of the tests, and if it serves the function then you market the product. The students go through the same processes when they are solving an engineering problem or designing a solution in the classrooms. They make observations, they connect the dots by using their creativity, they make predictions, they design, they test, evaluate and construct.

ISSN:2149-8504 (online)

Engineering nature of the lesson	My lesson focused on the relationship between pressure and volume and designing a system based on this principal. The students are asked to use this principal to make two balloons to rise faster or slower in the air. We designed two balloons with two different pressures in it and used Torricelli's gas law to see how they rise. This theory has guided the development of many engineering technologies so it is important that students understand that law. Scientists and engineers have used this theory to design systems. They have used it in designing perfume cans, in rocket design, in fire extinguishing technologies. Scientists and engineers have used this law and their creativity to solve problems and design products that make our lives better. These examples tell us that the main purpose of engineering design is to design solutions to solve problems. In my activity, we differed the amount of the gas in the balloons and tested to see which balloon would rise faster and discussed the reasons behind our observations and the implications of these observations for designing new products that can meet human needs or simplify their lives.
Justification as to why this lesson involves engineering design	It is engineering because students build a system, and they brainstorm, they test, they make observations and evaluations, and engage in questioning. For instance, students ask, why do we need to put so much gas in this balloon. They look at the fire extinguisher, they start to think about why is there pressure in these extinguishers? Further, they make observations about the elevation differences between the balloons, they figure out why there is less air pressure at higher elevations. They brainstorm, they interpret they came up with alternative ideas. You try and fail and try again to come up with an idea so it is not easy to design things. Students make observations, build systems, test and fail but during the process they apply their knowledge of science, and learn about the implications of scientific knowledge in engineering design and make connections between gas pressure and some systems such as rockets. I designed my lesson so when the students look at a rocket, they can start to think and relate these concepts to the rocket design. They say that when gas is heated it expand and the kinetic energy of the gas particles increase which then increases the pressure. So to manage the amount of pressure, we need math to do the calculations to adjust the amount of pressure. So my lesson has engineering design and science and math.

As this exemplary answer indicate participants have started to develop an informed understanding of engineering design and how science maybe taught through engineering design.

Justification for Teaching through Engineering Design

PSTs provided diverse responses as for the justification to teach through engineering design. These justifications ranged from an emphasis on the intellectual capital and professional workforce needed for country's economic prosperity, to its potential pedagogical benefits such as promoting students' systems thinking abilities, encouraging students to develop creative solutions to the problems facing different industries such as medical, environmental, defense and agriculture.

ISSN:2149-8504 (online)

Table 7.
Justification for Teaching through Engineering Design

	Themes	Frequency
Justification for teaching engineering design	Our country needs strong engineers for our econom-ic prosperity.	17
	It engages students in systems thinking	14
	Encouraging creativity: coming up with alternative solutions.	15
	Developing innovative systems/solutions to address various problems.	15
	Exposing students to the work of engineers/ increas-ing student interest in engineering fields.	17

One PST in particular, who we thought demonstrated a sophisticated understanding said the following as justification for teaching engineering design:

> Learning through engineering design makes learning more durable and teaches students to think more globally. This result is likely to happen because students learn by doing, and in a context relevant to their lives. Moreover, engineering design forces students to think creatively. When I bring the tools out, students are going to ask: What are we going to do today? They are going to think. When I ask them to design a product, they are going to think about how to put different parts together, think about what their products may look like, this is going to require them to think creatively.

As this exemplary statement shows, most participants were able to cite the pedagogical benefits of teaching STEM through engineering design.

Participants' Understanding of Pedagogical Demands of STEM Integration

Participants reported unique challenges that they experienced in designing the integrated STEM lessons in the context of this study and the course. Not surprisingly, as expected PSTs cited 1) lack of content knowledge, 2) lack of experience in engineering design, 3) lack of experience in designing integrated STEM lessons, 4) difficulty with coming up with problem cases as impediment to their abilities to design integrated STEM lessons.

Table 8.
Participants' Understanding of Pedagogical Demands of STEM Integration

	Themes	Frequency
Challenges experienced while designing the lesson	Lack of experience in designing integrated lessons.	17
	Lack of knowledge and experience in engi-neering design.	15
	Coming up with design-based problem cas-es.	17
	Problem with content knowledge made it difficult for me come up with a problem to make connections across disciplines.	17

Now that the PSTs had experienced learning through STEM integration and developed an integrated STEM lesson, we wanted to know what types of challenges they experienced during the process of lesson planning and the types of support and resources they thought they would need to become well-prepared for the task of teaching through STEM integration. Participants' experienced unique challenges, however, lack of experience

ISSN:2149-8504 (online)

with engineering design, lack of content knowledge, and lack of experience with designing integrated STEM lessons were cited to be the main hindrances to their abilities to design integrated STEM lessons. To expose our readers to the details of challenges that two PST's experienced in designing integrated STEM lessons we provide some quotes. One PST said the following regarding the challenges she experienced:

> I realized that I have gaps in my knowledge of science and skills in engineering design. I realized that I do not have experience in designing integrated STEM lessons, and to design better lessons, I will need mentorship and more practice. For instance, I initially only had students make observations, test their ideas, and acquire knowledge. I experienced some challenges in making connections to engineering and technology but I still do not think I did a great job with the engineering and technology component of my lesson.

Another PST focused on the conceptual and practical challenges he experienced with integrating engineering design into his lessons.

> I experienced the most difficulty with the engineering part. Because when we think of engineering we think of big projects, planes, bridges, we never think of design based thinking. Therefore, I was trying hard to make my students to construct something big but also something practical. It is hard to integrate engineering design in short activities. I also do not know much about the engineering design process myself. I realized that I need to have a more in-depth understanding of both the engineering design process and engineering practices. I need to develop skills needed for me to bring the concepts down to their level of understanding and skill levels. Not only do I need to understand the engineering design process but I also need to develop pedagogical knowledge needed for me to teach these skills to my students in an effective way.

These two exemplary statements show the unique challenges each PST experienced both conceptually and practically in designing engineering-based lessons. Both PSTs point out their lack of understanding of engineering design, as well as pedagogical knowledge needed for successfully integrating engineering design in their lessons.

Resources Needed for Teaching Science through STEM Integration

The participants expressed various ideas about types of resources they would need to successfully teach science through STEM integration. These ideas are summarized in Table 9.

Table 9.
Perceived Resources Needed for Teaching Science through STEM Integration

	Themes	Frequency
Resources needed to teach integrated STEM	Need a course on STEM integration	17
	Need mentorship to get it right.	11
	Need professional development.	17
	Need feedback from an expert.	14
	With more practice, I can do a better job with designing a STEM lesson.	9
	Lab space and materials for engaging students un hands-on STEM activities.	15

Participants made several suggestions for addressing their professional needs to become prepared for the task of teaching through STEM integration. All participants were in agreement in taking a methods course focusing on STEM integration, needing mentorship and feedback from an expert on their lessons and practice and needing a lab space for engaging students in hands-on STEM activities. While they pointed out several challenges and highlighted their needs for resources, all of the participants but two were confident that their

ISSN:2149-8504 (online)

pedagogical skills for integrated STEM would improve with practice once they are in their classrooms. One PST expressed that taking a hands-on course on STEM integration would help her to become better prepared. She said:

> I think I will greatly benefit from a course that taught us the engineering design process through hands-on activities. We could then apply our pedagogical knowledge to design engineering based integrated STEM lessons more easily for our students. I would feel more prepared to teach integrated STEM if I was provided with such learning experiences in my teacher preparation program.

Another PST said:

> To develop better lessons, I will need resources, tools but also professional development in this area. For instance, I need to hear from my professors or colleagues about the weaknesses in my lessons, and get ideas from them about different aspects of my lessons. I believe with more practice and feedback; I will eventually be able to design quality integrated STEM lessons from my students.

Another PST expressed that having ready-made STEM lesson modules would help her to teach STEM more effectively than she could now without teacher-proof lessons.

> I think I would prefer to have some ready-made lesson modules, with explanations both from a scientific, mathematical and pedagogical perspectives. These would help because I do not have a solid scientific or mathematical background. If I had these modules, I could self-learn the content before teaching it. I think some advanced training about pedagogy of STEM integration would also help but I am not sure if that training is available in schools.

Collectively, these statements show that PSTs believe that access to professional development both in content and pedagogy of integration and engineering design, and STEM related curricular resources would both help them to increase their efficacy to teach through STEM integration, and boost their pedagogical capacity to effectively integrate engineering design in their lessons.

Discussion

Research studies show that the way PSTs conceptualize STEM integration impacts how they integrate STEM content and engineering practices into their lessons and subsequently impacts what the students learn in the classroom (Diefes-Dux 2014; Estapa & Tank, 2017; Yeung & Lam, 2007; Guzey et al., 2016). The results show that PST's developed a "developing" understanding of STEM integration, and engineering design process. However, some of them struggled to transfer that understanding into pedagogical knowledge that held potential to promote students' acquisition of knowledge and skills aimed by integration. The PSTs experienced this struggle because they lacked a robust understanding of fundamental engineering knowledge and practices, had no experience in engineering design, and had limited content knowledge of science or mathematics.

Another important result that emerged from this study is that immersing PSTs in STEM integration activities, and guiding them to design STEM integration lessons brought about awareness regarding pedagogical demands of STEM integration and the gaps in their content knowledge. Our results also show that PST's became aware of the limitations of their conceptualizations of engineering design, importance of conceptual understanding of science and engineering design for effective integration, the need for professional development, and curriculum materials designed for purposeful integration. While their lessons reflected certain aspects of design-based STEM integration (as the interviews revealed), the majority of PSTs failed to make explicit references to the science/mathematical concepts that were the focus of the lesson. For instance, most of them only focused on the science content, ignoring the mathematoal connection. This is expected as primary school PSTs get limited opportunities (i.e., they take fewer number of science and math courses) to develop a sophisticated content knowledge needed to design content-heavy lessons.

These results are consistent with relevant literature (Estapa & Tank, 2017; Furner & Kumar, 2007; Kim & Bolger, 2017; Koirala & Bowman, 2003). For instance, Estapa and Tank (2017) after engaging preservice elementary teachers in a semester long professional development, where they had a triad of PST, supervising teacher and an engineering graduate student work together, design, implement and reflect on engineering based STEM lessons, found that even after a 16-week intervention, teachers experienced unique challenges with implementation of engineering design activities. More specifically, they failed to effectively integrate science and math content into their lessons. In comparison to the 16-week intervention in Estapa and Tan (2017)'s study, we immersed PSTs in STEM integration activities for 6 weeks in the context of a university course with no room for implementation. We argue that if the PSTs had been given the opportunity to implement their lessons and were provided opportunity to engage in collaborative reflection under guidance of university faculty, they would have developed a better understanding of STEM integration and pedagogical skills to effectively integrate across STEM subjects. However, we understand that these results would be possible if PST's were convinced of the benefits of STEM integration, had content knowledge of science and math concepts that are the target of integration and engineering design process. Finally, we think that in order for PSTs and any teacher for that reason to develop sophisticated pedagogical knowledge and skills for STEM integration, they would need to engage in practice of teaching integrated STEM, and collaborative reflection for a sustained period of time. Engaging in such practice and reflection would encourage PSTs and practicing teachers to notice and reflect on what works and what does not work and develop more responsive instruction.

Implications

While the experiences provided helped students to be exposed to the idea of STEM integration, and engineering design process, these experiences alone are not sufficient for PSTs to effectively design integrated STEM lesson and meaningfully enact them in the classroom to promote students' acquisition of engineering knowledge and skills. The results of this study can inform efforts to design courses, professional development programs for pre-service primary and elementary teachers, the two groups that have limited content knowledge and experiences in engineering design, science and math content in general (Fung et al, 2017; Gomez-Zwiep, 2008). Literature suggests that professional development programs must engage teachers in active learning, focus on content, engage participants in collaborative inquiry and reflection (Borko, 2004, Borko, Jacobs, Eiteljorg & Pittman. 2008; Garet, Porter, Desimone, Birman, & Yoon, 2001; Gamoran, Secada, Marrett, 2006; Guzey et al. 2014; Loucks-Horsley, Hewson, Love, & Stiles, 1997). However, with integration and engineering design being the new focus, new professional development models are called for. PSTs need not only learn about the content but also skills for purposeful and meaningful integration (Estapa &Tank, 2017; Moore et al. 2014). Further, while doing so they must also help students acquire problem solving skills, and develop creative solutions through engineering design (Cunningham and Hester 2007; Guzey, Moore, & Harwell, 2016). However, we know that majority of PSTs and practicing primary and elementary teachers have limited to no understanding of the engineering design process and skills associated with engineering practices (Hsu, Purzer, & Cardella, 2011; Van Haneghan, Pruet, Neal-Waltman, & Harlan, 2015). Therefore, we need not only make engineering design a central component of any professional development program but also, support teachers' implementation of STEM integration by providing them with curricular materials that use engineering design as the "organizing framework" for designing STEM-based learning experiences (Brophy et al. 2008; Cunningham and Lachapelle, 2014; Moore et al. 2014). Finally, curriculum materials designed in support of teachers' effective implementation of STEM activities, must come with educative curriculum materials for the teachers. These types of support mechanisms have been found to be useful for science teachers (Beyer & Davis, 2009; Davis & Krajcik, 2005). Moreover, professional development literature suggests that practice-based professional development programs create fruitful conditions for teachers to learn (Ball & Cohen, 1999: Birman, Desimone, Porter, & Garet, 2000). Therefore, we will follow these teachers into their classrooms and create diverse opportunities for them to learn about engineering design and pedagogy of STEM integration through collaborative inquiry and reflection in the form of lesson study (Lewis, 2002; Rock & Wilson, 2005). We encourage STEM education community to

ISSN:2149-8504 (online)

think about ways in which pre-service primary teachers can be supported to develop content and pedagogy of integration. Similarly, we need to think about theoretical frameworks to conceptualize STEM integration pedagogy and practical tools to measure teachers' pedagogical knowledge related to STEM integration.

References

Ball, & D. L. & Cohen, D. K. (1999). Developing practice, developing practitioners: Toward a practice-based theory of professional education. In Darling-Hammond, L. and G. Sykes. (Eds). *Teaching as the Learning Profession (pp. 3-32): Handbook of Policy and Practice*. San Francisco: Jossey Bass.

Baxter, J. A., Ruzicka, A., Beghetto, R. A. & Livelybrooks, D. (2014). Professional development strategically connecting mathematics and science: the impact on teachers' confidence and practice. *School Science and Mathematics*, *114*(3), 102–113.

Beane, J. A. (1995). Curriculum integration and the disciplines of knowledge. *Phi Delta Kappan*, *76*(8), 616–622.

Bennett J., & Holman J. (2002). Context-Based approaches to the teaching of chemistry: What are they and what are their effects?. In: Gilbert J.K., De Jong O., Justi R., Treagust D.F., Van Driel J.H. (eds) *Chemical Education: Towards Research-based Practice*. Science & Technology Education Library, vol 17. Springer, Dordrecht

Berlin, D. F. & Lee, H. (2005). Integrating science and mathematics education: historical analysis. *School Science and Mathematics, 105*(1), 15–24.

Beyer, C., & Davis, E. A. (2009). Using educative curriculum materials to support preservice elementary teachers' curricular planning: A comparison between two different forms of support. *Curriculum Inquiry*, *39*(5), 679-703.

Birman, B. F., Desimone, L. M., Porter, A. C., & Garet, M. (2000). Designing professional development that works. *Educational Leadership*, *57*(8), 28-33

Borko H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher*, *33*(8), 3–15.

Borko, H., Jacobs, J., Eiteljorg, E., & Pittman, M. E. (2008). Video as a tool for fostering productive discussions in mathematics professional development. *Teaching and Teacher Education*, *24*, 417–436.

Brophy, S., Klein S, Portsmore, M., Rogers. C. (2008). Advancing engineering education in K-12 classrooms. *Journal of Engineering Education*, *97*(3), 369–387.

Capraro, R.M., & Slough, S.W. (2008). *Project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach*. Rotterdam, The Netherlands: Sense Publishers.

Cervetti, G. N., Barber, J., Dorph, R., Pearson, P. D. & Goldschmidt, P. G. (2012), The impact of an integrated approach to science and literacy in elementary school classrooms. *Journal of Research in Science Teaching*, *49*(5), 631–658.

Childress, V.W. (1996). Does integration technology, science, and mathematics improve technological problem solving: A quasi-experiment. *Journal of Technology Education*, *8*(1), 16-26.

Clark, A.C., & Ernst, J.V. (2006). A model for the integration of science, technology, engineering, and mathematics. *The Technology Teacher*, *66*(4), 24-26.

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. London: Sage.

Coffey, A., & Atkinson, P. (1996). *Making sense of qualitative data*. Thousand Oaks, CA: Sage Publications.

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*. Sydney, NSW: Allen & Unwin.

Cunningham, C. M., & Lachapelle, C. P. (2014). Designing engineering experiences to engage all students. In S. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in pre-college settings: synthesizing research, policy, and practices* (pp. 117–142). Lafayette: Purdue University Press.

Cunningham, C. M., & Hester, K. (2007). *Engineering is elementary: an engineering and technology curriculum for children*. Honolulu: Proceedings of the American Society for Engineering Education Annual Conference and Exposition.

Diefes-Dux, H. A. (2014). In-service teacher professional development in engineering education: early years. In S. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in precollege settings: Synthesizing Research, Policy, and Practices* (pp 211–230). Lafayette: Purdue University Press.

Estapa, A. T., & Tank, K.M (2017).Supporting integrated STEM in the elementary classroom: a professional development approach centered on an engineering design challenge. *International Journal of STEM Education*, *4*(6), 1-16.

Frykholm, J., & Glasson G. (2005). Connecting science and mathematics instruction: pedagogical context knowledge for teachers. *School Science and Mathematics*, *105*(3), 127–141.

Fung, D., Kutnick, P., Mok, I., Leung, F., Lee, B. P. Y., Mai, Y. Y., & Tyler, M. T. (2017). Relationships between teachers' background, their subject knowledge and pedagogic efficacy, and pupil achievement in primary school mathematics in Hong Kong: An indicative study. *International Journal of Educational Research*, *81*, 119-130.

Furner, J. M. & Kumar, D.D. (2007). The Mathematics and Science Integration Argument: A Stand for Teacher Education. *Eurasia Journal of Mathematics, Science & Technology Education*, *3*(3), 185-189.

Gamoran A., Secada W. G., Marrett C. B. (2000). The organizational context of teaching and learning: Changing theoretical perspectives. In Hallinan M.T. (Ed.), *Handbook of research in the sociology of education* (pp. 37–63). New York: Kluwer Academic/Plenum.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915.

Gencer, S. A,. (2015). Fen Eğitiminde Bilim ve Mühendislik Uygulaması: Fırıldak Etkinliği. *Araştırma Temelli Etkinlik Dergisi*, 5(1), 1-19.

Gomez-Zwiep, S. (2008). Elementary teachers' understanding of students' science misconceptions: Implications for practice and teacher education. *Journal of Science Teacher Education*, *19*, 437-454.

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N.K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp 105-117). Thousand Oaks, CA: Sage Publications.

Gresnigt, R., Taconis, R., van Keulen, H., Gravemeijer, K & Baartman, L. (2014). Promoting science and technology in primary education: a review of integrated curricula. *Studies in Science Education*, *50*(1), 47-84.

Guzey, S. S., Moore, T. J., Harwell, M., & Moreno, M. (2016). STEM Integration in Middle School Life Science: Student Learning and Attitudes. *Journal of Science Education and Technology*, *25*(4), 550-560.

Guzey, S., Tank, K., Wang, H-H., Roehrig, G., and Moore, T. (2014). A High-Quality Professional Development for Teachers of Grades 3-6 for Implementing Engineering into Classrooms. *School Science and Mathematics*, *114*(3), 139-149.

Guzey, S. S., Moore, T. J., & Harwell, M. (2016). Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials. Journal of Pre-College Engineering Education Research, 6(1), 11–29.

Harwell, M., Philips A, Mareno, M., Guzey SS, Moore T (2015) A study of STEM assessments in Engineering, Science, and Mathematics Assessments for elementary and middle school students. *School Science and Mathematics*, *115*(2), 66–74.

Hsu, M-C; Purzer, S., & Cardella, M. E. (2011). Elementary teachers' views about teaching Design, Engineering, and Technology. *Journal of Pre-College Engineering Education Research* (J-PEER), *1*(2), 31–39.

Isaacs, A., Wagreich, P., & Gartzman, M. (1997). The quest for integration: school mathematics and science. *American Journal of Education*, *106*(1), 179–206, Kim, D., & Bolger, M. (2017). Analysis of Korean elementary pre-service teachers' changing attitudes about integrated STEAM pedagogy through developing lesson plans. *International Journal of Science and Mathematics Education*, 15(4), 587-605.

Koirala, H. P. and Bowman, J. K. (2003), Preparing middle level preservice teachers to integrate mathematics and science: Problems and possibilities. *School Science and Mathematics, 103*(3), 145–154.

Lam, C. C., Alviar-Martin, T., Adler, S. A. & Sim, J. B. (2013). Curriculum integration in Singapore: teachers' perspectives and practice. *Teaching and Teacher Education*, *31*, 23–34.

Lehman, J., Kim, W., & Harris, C. (2014). Collaborations in a community of practice working to integrate engineering design in elementary science education. *Journal of STEM Education: Innovations and Research*, *15*(3), 21-28.

Lederman, N. G. & Lederman, J. S. (2013). Is it STEM or "S & M" that we truly love? *Journal of Science Teacher Education*, *24*(8), 1237–1240.

Lehman, J. R. (1994). Integrating science and mathematics: perceptions of preservice and practicing elementary teachers. *School Science and Mathematics*, *94*(2), 58–64.

Lewis, C. C. (2002). *Lesson study: A handbook of teacher-led instructional change*. Philadelphia: Research for Better Schools.

Loucks-Horsley, S., Hewson, P., Love, N., & Stiles, K. (1997). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin Press.

Merriam, S. B. (2001). *Qualitative research and case study applications in education*. San Francisco: Jossey-Bass.

Miles, M., & Huberman, A. M. (1994). *Qualitative data analysis*. Thousand Oaks, CA: Sage Publications.

Mobley, M. C. (2015). *Development of the SETIS Instrument to measure teachers' self-Efficacy to teach science in an Integrated STEM Framework*. PhD Dissertation, University of Tennessee, 2015.

Moore, T. J. (2008). *STEM integration: Crossing disciplinary borders to promote learning and engagement*. Invited presentation to the faculty and graduate students of the UTeach Engineering, UTeach Natural Sciences, and STEM Education program area at University of Texas at Austin, December 15, 2008.

Mostyn, B. (1985). The content analysis of qualitative research data: A dynamic approach. In M. Brenner, J. Brown & D. Cauter (Eds.), *The research interview* (pp.115-145). London: Academic Press.Ring, E.A., Dare, E.A. Crotty, E. A., & Roehrig, G.H. (2017) The evolution of Teacher conceptions of STEM Education throughout an intensive professional development experience, Journal of Science Teacher Education, 28 (5), 444-467.

Riskowski J. L, Todd C.D., Wee, B., Dark, M, & Harbor, J. (2009). Exploring the effectiveness of an interdisciplinary water resources engineering module in eighth grade science course. *International Journal of Engineering Education*, *25*(1), 181–195.

Rock, T. C. & Wilson, C. (2005). Improving teaching through lesson study. *Teacher Education Quarterly*, *32*(1), 77-92.

Roehrig, G. H., Moore, T. J.,Wang, H. & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics*, *112*(1), 31–44.

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM. *Journal of Pre-College Engineering Education Research*, *2*(1), 28-34.

Sanders, M. E. (2008). STEM, STEMeducation, STEMmania. *The Technology Teacher*, *1*, 20–26.

Stinson, K., Harkness, S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration: Models and Characterizations. *School Science and Mathematics*, *109*(3), 153-161.

ISSN:2149-8504 (online)

Van Haneghan, J. P., Pruet, S. A., Neal-Waltman, R., & Harlan, J. M. (2015). Teacher beliefs about motivating and teaching students to carry out engineering design challenges: Some initial data. *Journal of Pre-College Engineering Education Research*, *5*(2), 1-9.

Wendell K, & Rogers, C. (2013). Engineering design-based science, science content performance, and science attitudes in elementary school. *Journal of Engineering Education*, *102*(4), 513–540.

Yeung, S. Y. S. & Lam, C. C. (2007). Teachers' conception of curriculum integration: a problem hindering its implementation in Hong Kong. *Education Journal*, *35*(2), 109–144.

ISSN:2149-8504 (online)

J-STEM

Journal of Research in STEM Education

j-stem.net