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An Examination of Preparation Experiences that Influence Technology and Engineering Educators' Teaching of Science Concepts

Session II: Research Experiences that Influence Technology and Engineering Educators' Content Selection

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What preparation experiences influence technology and engineering (T&E) educators' teaching of science concepts? The purpose of this research was to investigate the extent of the relationship between T&E educators' select science and T&E preparation experiences, and their teaching of science content and practices. This study, which utilized a fully integrated mixed methods design (Teddlie & Tashakkori, 2006), was conducted to inform the pre- and in-service preparation needs for T&E educators. A random sample of 55 Foundations of Technology (FoT) teachers across 12 county school systems within an ITEEA consortium state participated in an online survey, leading to eight teachers being purposefully selected for classroom observations. Data collected from the surveys and classroom observations were analyzed through Spearman's rho tests to examine the strength of the relationships between certain preparation factors and the teaching of science content and practices. These data were corroborated with FoT curriculum content analyses, classroom observation audio recordings and notes, and interview responses to help validate the results.

Introduction and Background

Both T&E education and science education have emphasized the importance of teaching cross-disciplinary science, technology, engineering, and mathematics (STEM) connections to prepare a more STEM-literate society (NAE & NRC, 2014). Technology and engineering (T&E) educators have been expected to integrate STEM concepts in the context of problem solving and engineering design since the release of the *Standards for Technological Literacy* (STLs) (ITEA/ITEEA, 2000/2002/2007). However, it was not until 13 years later that the *Next Generation Science Standards* (NGSS) tasked science educators with teaching of engineering content and practices (NGSS Lead States, 2013). In light of this, logic would dictate that following a decade of integration T&E educators would be expected to have greater preparation and experience with integrating cross-disciplinary concepts than do science educators, and therefore serve as a more viable population to examine the teaching of STEM content and practices (Love, Wells, & Parkes, under review). These mandates in science education to integrate cross-disciplinary concepts do not come without reservations though, as they place new demands on teacher preparation efforts to adequately prepare educators (Love, 2015).

PCK Research

A critical component of teacher preparation is developing candidates' pedagogical content knowledge (PCK). Lee Shulman (1987) proposed the concept of PCK which he defined as, "the blending of content and pedagogy into an understanding of how particular topics,

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problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8). Williams and Lockley (2012) later described it as, "a special blend of content knowledge and pedagogical knowledge built up over time and experience" (p. 468). As Love (2013) identified, there has been an extensive amount of research conducted on PCK within science (Abel, 2008; Gess-Newsome & Lederman, 2002; Hume & Berry, 2011; Loughran, Berry, & Mulhall, 2012; Magnusson, Krajcik, & Borko, 1999) and mathematics (Hill, Ball, & Schilling, 2008; Krauss, Baumert, & Blum, 2008; Manizade & Mason, 2011) education, but few studies have examined the PCK of T&E educators. Gumbo and Williams (2014) identified T&E teacher PCK as an important yet under-researched area. The aforementioned studies within STEM disciplines have utilized various methodologies to investigate teachers' PCK. However some studies, especially within science education, have focused on topic specific PCK (e.g., chemical equilibrium) which can be difficult to apply within or among subject areas.

Phillips, De Miranda, & Shin's (2009) research in industrial design education supported the concept of PCK being topic specific. They proposed that a teacher's content knowledge in a subject area (e.g., science, engineering) was distinctly different from a teacher's pedagogical knowledge, yet each were essential to classroom instruction. Phillips et al. concluded that the synthesis of these content and pedagogical knowledge bases elicited a unique form of topic specific PCK.

Through case study reflections, participation in workshops and teacher agreement meetings, and utilizing student portfolios, Jones and Moreland (2004) were able to show increases in T&E educators' PCK. They found these increased PCK levels resulted in enhanced knowledge about the nature of technology, specific technological knowledge, pedagogical approaches, better student teacher interaction, more appropriate learning outcomes, critical decision making, enhanced teacher confidence, and greater student learning. They recommended seven constructs of PCK that should be collectively developed for more effective T&E teachers and enhanced student performance. Fox-Turnbull (2006) found similar benefits to student learning associated with T&E educators' teaching. She attributed teachers' technological knowledge and effective teaching methods to enhanced student designs and procedural knowledge.

In connection with student learning and integrating STEM concepts, Hynes (2012) found experience to be a critical component of PCK. His examination of Project Lead the Way (PLTW) teachers' PCK found that those with increased years of teaching experience were able to make more connections to mathematics and science concepts within a PLTW unit. Additionally, those PLTW teachers with greater experience employed a more student-centered approach and spent more time engaging students through discussion.

In 2011 Rohaan et al. investigated how the science and technology PCK of primary school technology educators impacted teachers' ability to convert subject matter into meaningful effective activities. Their research found that PCK was commonly measured using time consuming multi-method evaluations, so they developed a multiple-choice PCK instrument called the Teaching of Technology Test (TTT). The TTT helped address concerns about the feasibility and lack of large-scale PCK studies (Abel, 2008). Rohaan et al. determined that the TTT was a reliable instrument that could predict teaching behavior and PCK reasoning, while providing implications for studying larger samples and making more generalizable conclusions.

The Content Representation (CoRe) instrument developed in science education to investigate teachers' PCK was tested among a group of early career science and T&E educators by Williams and Lockley (2012). Their study found that the CoRe instrument helped develop the T&E teachers' procedural and conceptual knowledge that contributes to their PCK. Additionally, it revealed that T&E educators spent more time than science educators defining the enduring ideas of a T&E topic because the field had a less structured epistemology. Gumbo and Williams (2014) later examined the PCK of T&E educators in South Africa and found significant differences among teachers' understanding of T&E education curriculum, pedagogy, and assessment. Specifically they found that some teachers viewed technology as complementary to science, while others treated the two subject areas as distinctly different entities. Similar to Phillips et al. (2009), Gumbo and Williams (2014) concluded that PCK is, "individual, unique, varies from class to class and changes over time" (p. 487).

As evidenced by the previously presented studies, PCK is a distinct knowledge integral to teaching and student learning, hence it should be a critical focus of teacher preparation efforts. With the STLs and NGSS calling for teaching of cross-disciplinary STEM concepts, the preparation experiences of T&E educators must be further examined to enhance their level of science PCK and teach STEM concepts more proficiently. T&E educators' PCK is often developed through T&E content and methods courses, a student teaching internship, and classroom experience. However, they often complete a limited amount of science content courses, and none if any science methods courses in their teacher preparation program (Litowitz, 2014; Love, in press; McAlister, 2004; Strimel, 2013).

Content Requirements Research

McAlister (2004) found that 29% of T&E teacher preparation programs in the United States required students to complete two science courses, and 38% required two lab based science courses. Only about 33%, 17%, and 21% of the programs reported that all of their T&E teacher candidates were required to complete a non calculus based physics, chemistry, or biology course respectively. McAlister noted that while non calculus based physics was the most commonly required course, most programs allowed students to select any two science courses, resulting in inconsistent science preparation across T&E teacher education programs. Litowitz (2014) conducted a similar study, finding that on average, 42% of T&E teacher education programs in United States required students to take Physics I, and 33% required students to take either a physics, a biology, or a chemistry course. His study also revealed that only one program required all students to complete an advanced level science course (Physics II).

Specific to Foundations of Technology (FoT) teachers, Strimel (2013) found that only 23%, 26%, 23%, and 19% reported completing two or more courses in physics, biology, chemistry, or environmental science respectively. A later study by Love (in press) revealed findings consistent with Strimel's 2013 research: 27%, 27%, 15% and 7% of FoT teachers had completed two or more courses in physics, biology, chemistry, or earth science respectively. The limited amount and variation of science preparation experiences completed by T&E educators' is alarming given the continually convergent paths of science and T&E education, and the increasing demands to prepare more STEM-literate citizens (Love, in press).

Findings from the literature exposing T&E educators' limited science preparation raises the question of how well T&E educators can demonstrate teaching of science content and practices embedded within T&E curricula. Furthermore, what specific preparation experiences are the most influential in enhancing T&E educators' science PCK? Investigating these questions could help inform teacher preparation efforts and better prepare T&E educators to adequately teach cross-disciplinary STEM concepts.

Methodology and Procedures

A fully integrated mixed design (Teddlie & Tashakkori, 2006) was used to answer the research questions and sub-questions. Mixing of quantitative and qualitative data occurred at all levels from the conceptualization to the inferential stages. The FoT course was specifically targeted since it was an internationally recognized curriculum that satisfied various STEM education standards, and teachers within consortium states were under agreement to implement the curriculum with fidelity. This addressed Gumbo and Williams's (2014) suggestion that PCK research should target common themes teachers deal with in T&E education.

Data collection began with the researcher analyzing the FoT lesson plans provided by ITEEA using content analysis (Vaismoradi, Turunen, & Bondas, 2013). Content analysis is a qualitative method used to describe characteristics that emerge from the content of a document (Bloor & Wood, 2006). Within the five units, only two lessons (Design: Energy and Power, and Troubleshooting: Ohm's Law) were found to have a substantial amount of embedded science content. The researcher identified all key science concepts from these two lessons to inform what they should be observing during their visit.

The lesson plan analysis was followed with the administration of the T&E Educators' Science PCK (TEES-PCK) survey instrument. With permission, the survey was administered to 12 county school systems in an ITEEA consortium state that had the largest population of FoT teachers. The survey was sent to 233 FoT teachers using the Qualtrics survey software, which yielded 55 complete responses. This resulted in a 24% (55/233) response rate which was acceptable according to Nulty's (2008) analysis of online survey response rates. The results from the TEES-PCK were recorded in a spreadsheet to help separate participants into three categories (novice, intermediate, and veteran) according to the median and quartiles of their reported years of teaching experience. After approximately the same number of teachers were placed into a teaching experience category, the mode for each survey question was identified according to each of the experience categories. From these mode values, participants' responses were rated low, average, or high among other teachers in their experience category, which allowed teachers with unique preparation characteristics to emerge (see Appendix H of Love, 2015). Eight participants deemed to have either low or high preparation factors according to their experience category were then purposefully selected for the classroom observation and interview portions of this study. This purposeful selection allowed the researcher to ensure participation of FoT teachers along the entire spectrum of experience and preparation levels since research has shown teaching experience to be one of the greatest indicators of PCK levels (Shulman & Hutchings, 2004; Williams & Lockley, 2012). A sample size of eight participants was determined to be sufficient for the observations and interviews based on qualitative methodology research, which found that three to five participants are adequate for qualitative studies (Collins, Onwuegbuzie, & Jiao, 2007; Creswell, 2002; Onwuegbuzie & Leech, 2005). Additionally, qualitative T&E education PCK studies (Hynes, 2012; Hynes, Crismond, & Brizuela, 2010; Jones & Moreland, 2004; Williams & Lockley, 2012) have found sample sizes of five or less ample for data analysis.

Next, classroom observations were conducted using a modified version of the Reformed Teaching Observation Protocol (RTOP) instrument (Sawada et al., 2000). The RTOP was useful in helping to quantify qualitative observations for use later in correlational analyses. The eight purposefully selected participants were observed teaching one of the science embedded FoT lessons for one class period. Lomas and Nicholas (2009) found it adequate for one observer to use the RTOP for a single classroom observation (about an hour) to rate each teacher. Audio recordings of the observed lessons were linked to the researchers' notes using the AudioNote software.

Immediately following the observation, participants were interviewed using questions adapted from Park, Jang, Chen, and Jung's (2011) PCK interview instrument. The observation notes, audio recordings, and interview responses helped to corroborate and validate what was observed according to what was expected from the lesson content analysis. Lastly the RTOP ratings, and TEES-PCK demographic and preparation data were entered into SPSS to determine if there was an identifiable association between preparation experiences and demonstrated PCK levels. To test for this relationship Spearman's rho was deemed the most appropriate measure since observation participants were purposefully selected, resulting in a non-Gaussian population, and the RTOP ratings and preparation experiences were ordinal variables that could be ranked (Sheskin, 2011). Figure 1 displays all data collection points used in answering the research questions and sub-questions of this study.

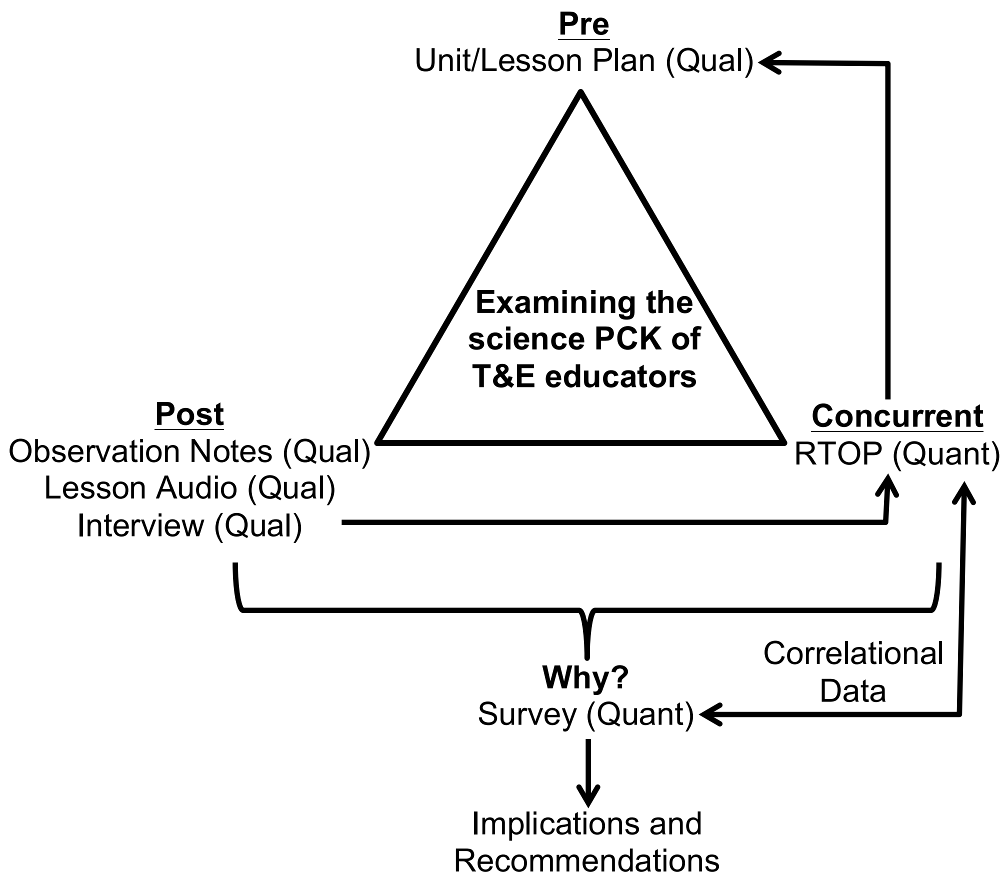

Figure 1. Triangulated mixed methods design for this study. Arrows denote where that data was used to corroborate findings from other phases. Reproduced from "Examining the Extent to Which Select Teacher Preparation Experiences Inform Technology and Engineering Educators' Teaching of Science Content and Practices," by T. S. Love, 2015, Blacksburg, VA: University Libraries, p. 89. Copyright 2015 by Virginia Polytechnic Institute and State University.

Research Questions and Sub-Questions

This study was guided by the following research questions and sub-questions examining the teaching of key science content and practices embedded within the FoT curriculum:

RQ1: What preparation experiences inform T&E educators' teaching of science content?

RQ1-SQ1: To what extent do select *science-related* preparation experiences influence FoT instructors' teaching of embedded *science content*?

RQ1-SQ2: To what extent do select *T&E-related* preparation experiences influence FoT instructors' teaching of embedded *science content*?

RQ2: What preparation experiences inform T&E educators' teaching of science practices?

RQ2-SQ1: To what extent do select *science-related* preparation experiences influence FoT instructors' teaching of embedded *science practices*?

RQ2-SQ2: To what extent do select *T&E-related* preparation experiences influence FoT instructors' teaching of embedded *science practices*?

Instrumentation

The following instruments helped collect data to address the research questions and sub-questions. A pilot study was implemented to refine the instruments and inform data collection. Presented below are descriptions of the instruments, procedures used to develop them, and methods to establish reliability.

TEES-PCK Survey Instrument

The TEES-PCK survey was adapted from a amalgam of science and mathematics education PCK instruments to collect data on participants' self-efficacy by using the Science Teaching Efficacy Belief Instrument (STEBI) (Riggs & Enochs, 1990), and their preparation experiences and demographics (Ball & Hill, 2008; Cwik, 2012; Perez, 2013). It was administered online, consisted of a series of multiple selection questions, and took approximately 30 minutes to complete. The 25 modified STEBI questions in Section II of the survey were comprised of 5 point Likert scale items, and were found to have high reliability values from Cronbach's alpha analyses (Love, in press). Table 1 summarizes the type of data collected from each section of the TEES-PCK survey instrument. More details about the creation of this instrument can be found in Love (in press), and the full survey instrument can be found in Appendix G of Love (2015).

Table 1

Descriptions of the TEES-PCK Survey Instrument By Section

Section	Data Collected	Description
I	Contact information	Name and email address
II	Self-efficacy	Adapted from the STEBI instrument (Riggs & Enochs, 1990).
III	Teacher preparation experiences	High school courses, path into teaching, and degrees held.

(continued)

Table 1 Continued

Section	Data Collected	Description
IV	Undergraduate coursework	Types and amount of science, technology, engineering, and math courses completed.
V	Graduate coursework	Types and amount of science, technology, engineering, and math courses completed.
VI	Informal non-collaborative experiences	Types and amount of time helping with clubs and activities, reading science or T&E literature, and participating in professional development.
VII	Informal collaborative experiences	Types and amount of activities, committees, professional development, conferences, and collaborations with other teachers.
VIII	Demographic and background characteristics	Gender, ethnicity, age, settings grew up and teaching in, years and areas of teaching experience, certifications.

RTOP Observation Instrument

The renowned RTOP (Sawada et al., 2000) was modified for this study to measure pedagogical practices and teaching of content in both T&E and science. This instrument has been widely used to examine the reformed teaching practices of science educators. Sawada et al. had established strong interrater reliability (r^2=.954, $p<.01$) of the instrument through classroom observations, and also strong internal consistency reliability (Cronbach's α=.97) of the instrument items. It was deemed as the best suited observation tool for this research due to its alignment with national science and mathematics standards. Taylor et al. (2013) deemed the RTOP adequate to measure teacher practice, and its alignment with the NGSS's recommendations for research-based instructional reform made it appropriate for this study. Taylor et al. found the construct validity of four out of the five subscales to be very good predictors (r^2=.941 and above) of the overall reliability score, supporting the validity of the RTOP items. Since, the RTOP was created prior to the NGSS, it needed modified to separately examine the teaching of both science *and* engineering content and practices. Specifically sub scale 4 of the RTOP which measured teaching of content, was modified by a panel of experts to separately rate observed teaching of content *and* practices (PCK) of both science *and* T&E. Additionally, the language within the instrument was adapted to match that of the NGSS, allowing it to collect data in alignment with the new standards. To help increase the consistency of the ratings, a rubric operationally defining each item in sub scale 4 was created using criteria from the RTOP Reference Manual (Sawada et al., 2000). This instrument was tested by a panel of Integrative STEM Education experts over three FoT lessons. Through multiple rounds of arbitration they were able to achieve acceptable interrater agreement of 83% (Howell, 2007), ensuring that the researcher could use it independently and be expected to rate the same as the panel of experts (Love et al., under review). Achieving interrater reliability and gaining experience using the modified RTOP gave the researcher confidence to independently use the instrument to accurately rate observed teaching strategies. The full observation instrument, sub scale rubric, and more details about the modification of this instrument can be found in Love et al. (under review).

Interview Protocol

The interview protocol included questions from Park et al. (2011) that were deemed the most appropriate for this study because they were originally created to collect data examining the correlation between teachers' PCK levels and reformed teaching ratings from the RTOP. The instrument items were adapted to specifically ask about teaching strategies regarding key science content observed (or missing) from the FoT lesson, and also preparation experiences that informed their teaching of science and T&E concepts. The interview responses helped corroborate and validate the observed teaching strategies rated on the RTOP. The full interview instrument can be found in Appendix M of Love (2015).

Participants

Survey participants. As described previously, all FoT teachers from 12 county school systems in an ITEEA consortium state were invited to participate in the online TEES-PCK survey. The majority of survey participants were Caucasian (93%) males (73%) with a mean age of 43. On average they had taught for 13 years, five of which they spent teaching FoT (Love, in press).

Observation participants. From the survey participants, eight teachers with unique preparation experiences were purposefully selected for the observation and interview phases. Those who reported participating in more or less experiences than the mode for their teaching experience category were determined to have a unique preparation. Most observation participants identified themselves as tinkerers, stating that they experimented with tools and machines when they were growing up. One individual was a former engineer, two had family members who were engineers, and three participants had worked in technical fields prior to teaching. Almost all observation participants completed at least one course in each of the following areas: high school biology, high school technology education, undergraduate biology or space science, and undergraduate T&E teaching methods. Two teachers did not take any physics courses in high school, while three reported taking at least one undergraduate physics course, and one instructor had completed a graduate level physics course. Half of the participants helped with a robotics club or the Technology Student Association (TSA) at their school. Within the past three years, seven teachers had attended a state T&E conference, and two attended a similar conference at the national level. For six or more hours a year, four of the teachers reported reading science literature, and four participated in an online collaborative science education network. Three individuals also delivered workshops about teaching T&E education. Most notably, one participant had served as the president of a national T&E education association as well as a writer and pilot site for the STLs. Additionally, one participant served as a writer for the FoT assessment items, and another participant was a national teacher trainer for the FoT curriculum.

Overall, the observed participants were predominantly white males certified to teach T&E education, with an average age of 48 years old, and a mean number of 18 years teaching experience. Only two participants had experience teaching science, which was a maximum of two years, but approximately half of the participants reported taking a higher education course that discussed methods for teaching interdisciplinary STEM concepts. All participants had attended some form of training to learn how to teach the FoT curriculum (Love et al., under review).

Findings

TEES-PCK Survey

Almost half (44%) of the participants possessed a master's degree, but only 84% percent were certified to teach technology education. Over half (53%) of the participants held certifications in an array of other areas, the most common being business education. Most (68%) held a degree in technology education, industrial arts (11%), business education (9%), or health education (8%). Roughly three quarters (73%) of the participants had completed a teacher preparation program and slightly more than half (51%) had attended some form of FoT training. In preparation to teach STEM concepts, (73%) of participants reported taking at least one higher education course regarding methods to integrate science and math concepts within T&E education.

In regards to coursework completed, almost all participants (98%) had taken a biology course, and 85% had completed a chemistry course in high school. Physics was taken the least (64%) among all high school science classes. When examining their undergraduate science coursework, biology (27%) and physics (27%) were most frequently taken. Further analysis revealed that very few completed a biotechnology (18%) or science methods (15%) course. Furthermore, less than seven percent completed a graduate level science content (physics, biology, chemistry, space science) or science methods course.

Informal collaborative and non-collaborative experiences were examined in addition to formal coursework. Within the past three years most participants (58%) did not engage in any clubs or after-school activities, but 25% of those that did helped with a robotics club. Participating teachers reported spending more time reading literature and partaking in workshops/in-service sessions in T&E education than science education. Additionally, they reported spending more time participating in informal collaborative T&E education experiences than science education experiences (e.g., observing classes, consulting with curriculum specialists, joining collaborative teacher networks, serving on committees or task forces).

About 25% of the FoT teachers had attended a T&E conference within the past three years, and only nine percent attended a similar science conference. While attending these conferences, most teachers (35%) reported attending only T&E sessions, but 18% attended a mix of science and T&E education sessions. When asked what other teachers they collaborate with most frequently, 36% of participants reported working with T&E teachers on a daily basis, while 65% reported never collaborating with biology teachers, and 51% claimed they never consulted their school's physics instructor. More detailed findings from the TEES-PCK are reported in Love (in press).

Classroom Observations

Observation notes. During classroom observations the researcher noted that although each teacher received the same curricular resources from FoT, there was much variation in the way the lessons were delivered. Three teachers used the FoT worksheet which tasked students with calculating the energy usage of appliances at home. Despite a sense of confusion among the students, none of the teachers demonstrated step-by-step procedures for the calculations nor did they explain what the units (e.g., kilowatts) signified. Findings from the survey would suggest that the participants had adequate preparation to teach these concepts (e.g., coursework in power, energy, and transportation [PET], electronics, algebra, statistics).

Variations in teaching styles also emerged during observations. For example, two teachers presented their lessons almost verbatim from the FoT PowerPoint, while the other six modified the FoT lesson for reasons they later discussed in their interview, such as lack of funding for the suggested materials. Approximately half of the teachers lectured about content for the entire class period, while the other four participants divided the class time between lecture and lab activities. Five of the participants used the PowerPoints provided by FoT while three used outside presentations, created their own PowerPoints, or did not use PowerPoints because they relied on class discussions and demonstrations.

The observations revealed examples of teachers who demonstrated more appropriate strategies for teaching science content and practices than others. During one observation the students were better able to see and understand electromagnetic energy when a teacher used a hand crank generator to illuminate a bulb. Less effective examples were seen when two teachers attempted to clarify the laws of thermodynamics by describing them as imaginary blocks and containers.

Almost all of the participants reported difficulties with teaching the entire FoT curriculum in the limited time that they interacted with students. Some teachers only saw students for 45 minutes every other day during a semester, forcing them to select only a few FoT units to teach. When given the choice, they admitted that they selected more T&E focused lessons because they were more comfortable with teaching those topics. In addition, participants expressed that they rarely taught the embedded key science concepts (e.g., thermodynamics, nuclear power) in great detail unless it was critical to the end of unit design challenge or subsequent units.

The interviews further revealed that five participants were uncomfortable with teaching targeted science concepts (e.g., thermodynamics, fission) because they believed it was too advanced for the types of students enrolled in FoT. Also, six participants believed they only scratched the surface of science concepts within the lesson, and that it was the science department's role to teach them in greater detail. Half of the teachers specifically told students that the science concepts would be covered in more detail within their physics or chemistry classes. Despite their discomfort and difficulty with teaching science concepts, during the interviews none of the teachers described teaching lessons in collaboration with their school's science department. However, six participants expressed that they borrowed equipment and shared ideas with their school's physics teachers, but not for the intent of teaching science and T&E concepts concurrently.

It was observed that five of the participants assumed students would be able to apply targeted science concepts to technological design problems in FoT. For example, these instructors mentioned biomass and nuclear energy but did not explain the scientific principles (e.g., atoms, fission) behind them. They simply presented the term, defined it, and then continued on with the lesson. In these cases students appeared to struggle making the connection and needed scaffolding which was not provided. Overall, the teachers viewed FoT as a survey course intended to expose students to various T&E concepts, and if interested, students could take an advanced T&E education course to further examine advanced STEM connections.

The researcher noticed that two teachers had students who were more engaged, which was apparent from the observed interest by students in the lesson and the amount of intriguing questions they posed. These two teachers scored the highest in the RTOP science and T&E

practices ratings. Their ability to interrelate science and T&E content through engaging strategies enhanced students' inquiry and promoted creative designerly thinking (McRobbie, Stein, & Ginns, 2001). It became apparent that the teachers with increased preparation experiences had more interaction with their students during the lesson as opposed to the other participants who delivered predominantly teacher-centered lessons. Encouraging student participation helped maintain student interest by allowing them to determine the focus of the lesson relative to the targeted FoT content.

Surprisingly, only two teachers grounded the targeted content in engineering design or problem-based learning. Six of the lessons included a prescribed set of instructions that merely required the students to mimic what the instructor demonstrated (e.g., soldering a component, wiring an outlet). Most participants provided students with the information they needed rather than encouraging the application of higher order thinking skills through predicting, designing, building, testing, and analyzing their ideas.

Lastly, during the observations it was difficult to distinguish if the highest rated participants were teaching an applied science or a T&E education class. Their ability to intricately integrate science and T&E concepts in harmony was a skill which the other teachers had not mastered or did not demonstrate during the observation. Upon further analysis of the TEES-PCK survey data, it was discovered that the two highest rated teachers reported reading a significant amount of science education literature, delivered science and T&E workshops, served on science education committees, and consulted with a science curriculum specialist within the previous three years. This led the researcher to conduct correlational analyses to examine the relationship between participants' preparation experiences from the TEES-PCK survey and their RTOP ratings. The vignettes in Appendix O of Love (2015) provide more detailed accounts of the full qualitative findings regarding how T&E educators taught key science content and practices embedded within FoT.

RTOP ratings. When examining the mean RTOP ratings, it is evident that participants demonstrated higher proficiency in teaching T&E content and practices. In regards to teaching of science content, they received a mean score of 9.6 (48% proficient) and for science practices the mean rating was 5.8 (29% proficient). Four teachers achieved a six (30% proficient) or lower for teaching of science content, and three earned a score of one (5% proficient) for their teaching of science practices. Conversely, teachers demonstrated mean ratings of 13.6 (68% proficient) for teaching T&E content and 7.6 (38% proficient) for T&E practices. Examining these scores in greater detail revealed that there were only three teachers who scored nine (45% proficient) or lower for teaching T&E content, but three who scored a two (10% proficient) or lower for T&E practices (Table 2).

Table 2

Observed Content and Practices Ratings

	Ratings for Teaching of Science and T&E Concepts			
Participant	Category and Rating			
	SC	T&E C	SP	T&E P
Teacher 1	6	7	1	1
Teacher 2	9	17	6	12
Teacher 3	3	7	1	1
Teacher 4	17	20	10	16
Teacher 5	19	20	15	16
Teacher 6	3	9	1	2
Teacher 7	14	19	7	6
Teacher 8	6	10	5	7
Mean	9.6	13.6	5.8	7.6

Note: SC=Science Content; T&E C=Technology and Engineering Content; SP=Science Practices; T&E P=Technology and Engineering Practices. Scores for each category range from 0-20, with higher scores indicating a greater rating. Adapted from "Modifying the RTOP to Examine Teaching of Science, and Technology and Engineering Content and Practices," by T. S. Love, J. G. Wells, and K. A. Parkes, under review.

Survey and Observation Correlational Data

Given the extent of data collected, only those preparation experiences which were found to have statistically significant correlations with teaching of science content and practices were reported in the following sections. To see the full list of preparation factors with their corresponding r_s and p values, please refer to Appendix Q of Love (2015).

Science Content (RQ1)

Science experiences and teaching of science content (RQ1-SQ1). The Spearman's rho (.798) between number of physics courses completed in high school and participants' teaching of science content rating was significant (.018) at the 0.05 level. The total number of science courses taken in high school was also found to have a strong positive correlation (.777) and be statistically significant (.023). These results indicate that the more science courses a T&E teacher took in high school, especially physics, the better prepared they could be expected to teach the science content embedded within the FoT curriculum. Further analysis revealed that undergraduate physics courses had a strong correlation (.773) as did undergraduate earth science courses (.718), and they both showed statistical significance of .024 and .045 respectively. The delivery of science in-service training had a strong positive correlation (.765) with teaching of science content and was statistically significant (.027). This would suggest that those teachers who deliver science professional development would be expected to demonstrate higher RTOP ratings for teaching science content. The Spearman's rho for not participating in any science professional development was found to have a significantly (.018) strong negative correlation (-.798) with observed teaching of science content ratings. As a result, no participation in science professional development activities and level of teaching science content would be expected to decrease together. In contrast to the other preparation factors that showed an association between science experiences and increase in science content rating, those who did not help with any after school science clubs had a strong correlation (.718) and significant (.045) association with the observed rating for teaching science content. This means that as the amount of after school science clubs a teacher helped with decreased, their rating for teaching of science content would be expected to increase (Table 3).

Table 3

Spearman's rho Correlation Table of Amount of Science Experiences and Teaching of Science Content

Measure	HS Physics	Total HS Science Courses	UG Physics	UG Earth Science	Deliver Sci. In-service	No Sci. PD	Helped with No Clubs
Science Practices							
r_s	.798	.777	.773	.718	.765	-.798	.783
p	.018	.023	.024	.045	.027	.018	.022
N	8	8	8	8	8	8	8

Note: HS = High School; UG = Undergraduate; Sci. = Science; PD = Professional Development; Clubs = After school clubs.

T&E experiences and teaching of science content (RQ1-SQ2). Analyses revealed that the only high school, undergraduate, or graduate T&E courses which significantly impacted participants' teaching of science content were undergraduate robotics courses. There was a strong positive correlation between number of undergraduate robotics courses and teaching of science content; the Spearman's rho was .741 and was significant with a p-value of .035. However, there were a few informal preparation experiences found to also have to a significant influence on participants' teaching of science content. It was found that if a T&E educator mentored another T&E teacher, this had a strong positive correlation (.765) and was statistically significant (.027), meaning that the amount of time spent mentoring a T&E teacher and the mentor's science content rating would increase together. Delivering T&E education in-service also had similar results yielding a very strong positive correlation (.883) and statistical significance (.004) to suggest that FoT teachers' rating for teaching science content would increase with the amount of T&E education in-service they deliver. Lastly, identical to the relationship reported for helping with after school science clubs and teaching of science content (Table 3), it was determined that those teachers who did not help with any after school T&E clubs had a statistically significant (.045) strong positive correlation (.718) with teaching of science content. From this it could be concluded that as the amount of time spent helping with T&E clubs decreased, the level at which participants taught science content increased (Table 4).

Table 4

Spearman's rho Correlation Table of Amount of T&E Experiences and Teaching of Science Content

Measure	UG Robotics Course	Mentor T&E Teacher	Deliver T&E In-Service	Helped with No Clubs
Science Content				
r_s	.741	.765	.883	.718
p	.035	.027	.004	.045
N	8	8	8	8

Note: UG = Undergraduate; Clubs = After school clubs; T&E = Technology and Engineering Education.

Science Practices (RQ2)

Science experiences and teaching of science practices (RQ2-SQ1). Similar to the Spearman's rho findings for research question one sub-question one regarding science content (Table 3), there were some comparable results for this research question examining science practices. Again, high school physics, total high school science, undergraduate physics, and undergraduate earth science courses all showed strong positive correlations with teaching science practices and were significant at the 0.05 level. The item with the strongest correlation (.866) and highest significance (.005) was the amount of high school physics classes completed. Based on these results, a T&E educator's rating for teaching science practices would have a tendency to increase and decrease with all of the courses mentioned above. Similar to the results found in research question one, sub-question one (Table 3) that examined teaching of science content, there was a strong positive correlation (.775) between delivering science in-service and teaching of science practices significant (.024) at the 0.05 level. This signifies that teaching of science practices can be expected to increase or decrease with the amount of science in-service delivered. The number of science committees served on was found to have a very strong positive correlation (.811) with science practices and was statistically significant (.015). From this it can be concluded that T&E educators' rating for science practices and number of science committees they serve on increases or decreases together. Also, the length of FoT training revealed a strong positive correlation (.803) with teaching of science practices, which was statistically significant (.016). This indicates that the T&E educators' rating for science practices increases with the length of FoT training attended. Similar to those results shown in Table 3 regarding science content, it was determined that there was a strong positive correlation (.783) between not helping with any after school science clubs and ratings for science practices. This elicited a statistical significance of .022, suggesting that higher ratings for teaching of science practices can be expected in conjunction with less time spent helping with after school science clubs (Table 5).

Table 5

Spearman's rho Correlation Table of Amount of Science Experiences and Teaching of Science Practices

Measure	HS Physics	Total HS Science Courses	UG Physics	UG Earth Science	Deliver Sci. In-service	Sci. Committees	Length of FoT Training	Helped with No Clubs
Science Practices								
r_s	.866	.755	.783	.783	.775	.811	.803	.783
p	.005	.030	.022	.022	.024	.015	.016	.022
N	8	8	8	8	8	8	8	8

Note: HS = High School; UG = Undergraduate; Sci. = Science; Clubs = After school clubs.

T&E experiences and teaching of science practices (RQ2-SQ2). Comparable to the results for teaching of science content (Table 4), the only T&E course found to have a significant influence (.032) on the teaching of science practices was undergraduate robotics (Table 6). This course was found to have a strong positive correlation (.751), meaning that the rating for science practices and number of undergraduate robotics courses completed increase or decrease together. As displayed in Table 4, the delivery of T&E education in-service and helping with no after school T&E clubs had a statistically significant correlation with teaching of science content. Similar results were uncovered in relation to the teaching of science practices (Table 6). The amount of hours spent delivering T&E education in-service had a very strong positive correlation (.894) with the ratings for science practices and was statistically significant (.003). This indicates that T&E educators who spend more hours delivering T&E education in-service would be expected to demonstrate higher levels science practices. Also consistent with Table 4 was the finding that helping with no after school T&E education clubs had a strong positive relationship (.783) with teaching of science practices and was statistically significant (.022). Ironically, this would suggest that the less T&E after school clubs a teacher helps with, the greater proficiency they would demonstrate in teaching of science practices. It was found that collaborating with T&E educators had a strong positive correlation (.720) with science practices ratings and was statistically significant (.044) at the 0.05 level. This reveals a new finding that science practices ratings would increase with the amount of time spent collaborating among other T&E educators (Table 6).

Table 6

Spearman's rho Correlation Table of Amount of T&E Experiences and Teaching of Science Practices

Measure	UG Robotics Course	Collab. w/ T&E Teacher	Deliver T&E In-Service	Helped with No Clubs
Science Content				
r_s	.751	.720	.894	.783
p	.032	.044	.003	.022
N	8	8	8	8

Note: UG = Undergraduate; Clubs = After school clubs; Collab. w/ = Collaborates with; T&E = Technology and Engineering Education.

Interview Findings

Participant interviews helped corroborate what the researcher observed and increased the validity of the RTOP ratings. Their responses supported the significant influence that high school science courses (especially physics), higher education science courses, and the delivery of science in-service were found to have from the Spearman's rho analyses. Additional influential factors that emerged among the interviews were: prior experience teaching electronics courses, attending professional STEM education association conferences, collaborating with T&E teachers, collaborating with physics teachers, prior science and T&E work experience (e.g., construction, engineering), high school and higher education T&E education courses, collaborating with family members who were engineers, and tinkering with materials and tools growing up.

The influence that robotics courses had on teaching science content and practices was not mentioned during the interviews despite showing significance in the Spearman's rho tests. The Spearman's rho analyses revealed that the less time teachers spent helping with science and T&E after school clubs, the more proficient they were at teaching science content and practices. During the interviews teachers described that instead of helping with after school clubs, they spent that time participating in other informal preparation experiences they believed to be more beneficial (e.g., professional learning communities). Participants strongly believed that knowledge about and experience with the FoT curriculum (e.g., helping write the FoT assessment items, delivering the FoT training, contributing to the writing and piloting of lessons) increased their proficiency of teaching science concepts. They stated that this allowed them to spend additional time preparing to teach key concepts in greater detail because they were more familiar with the T&E content in the lessons and were better aware of the challenges that may arise.

Conclusions

As with any research, there were a number of limitations that existed within this study. One limitation was the exclusion of participants with the median preparation experiences since those observed were purposefully selected based upon preparation experiences above or below the mode. This study had a homogenous sample for both the survey and classroom observations since involvement relied upon voluntary participation of FoT teachers from 12 school systems within one consortium state. For this reason the results cannot be generalized beyond the participating teachers within those school systems. Despite achieving an acceptable interrater reliability percentage and research supporting the use of the RTOP by a single observer for one lesson (Lomas & Nicholas, 2009), the reported observation ratings in this study were the findings of one researcher. The observer could only report on what was seen during his classroom visit – a snapshot of the teachers' yearly instruction. Furthermore, the PCK findings were limited to data collected from only the TEES-PCK, RTOP, and interview instruments.

As the findings from the TEES-PCK survey, RTOP, observation notes, interview responses, and Spearman's rho analyses suggest, teachers demonstrated less proficiency in teaching science content (48% proficient) and practices (29% proficient) than T&E content and practices. This overall lack of proficiency would not be expected according to the breadth and amount of formal science coursework and informal science preparation experiences reported by the eight participants. This indicates that T&E educators' science preparation experiences lack the necessary rigor to prepare them for fully teaching integrative concepts. Further research is needed to examine the quality of these experiences.

The observations and interviews corroborated the significant influence that curricular knowledge (Shulman, 1987) had on participants' teaching of science content and practices. This reinforces the importance of providing sufficient training and support to help instructors teach the STEM concepts embedded within curricula more proficiently. The Spearman's rho tests found that the only T&E course with a statistically significant influence on teaching of both science content and practices was undergraduate robotics. When asked about this, participants explained that the application of electronics theory in a hands-on context like robotics was beneficial for teaching the science that is part and parcel of T&E concepts. From this it can be concluded that providing ample opportunities for T&E educators to apply STEM content through hands-on T&E experiences is integral to prepare them for teaching STEM concepts more thoroughly.

In addition to taking extra robotics courses, this study suggests that the more high school and undergraduate science courses (especially physics) T&E educators complete, the better prepared they will be to teach embedded science content and practices. Informal experiences found to have significant influences on teaching of both science content and practices were the delivery of T&E in-service, delivery of science in-service sessions, and not helping with after school clubs. In the interviews participants cited the delivery of T&E and science in-service sessions as beneficial for enhancing their ability to teach interdisciplinary STEM concepts. Therefore, one could conclude that these opportunities provide a valuable experience in which T&E educators' have to develop an advanced understanding of STEM content to model better interdisciplinary teaching practices to others. T&E educators should be strongly encouraged to help deliver such in-service sessions. Lastly, the findings suggest that T&E educators should be cautious about spending too much time helping with after school clubs which could be spent partaking in more influential experiences (e.g., professional learning communities).

Other interesting findings that emerged from this study were the almost identical results between participant demographics from this research and those from Ernst and Williams's (2014) national T&E teacher study. Ernst and Williams (2014) found that most of T&E educators were Caucasian (92%) males (75%) over 45 years old, who had been teaching for an average of 15 years, had completed a teacher preparation program (78%), and were certified to teach T&E education (86%) (Love, in press). This highlights the lack of diversity among T&E educators in regards to race, gender, and age. However, it concludes that there is quite a variance among preparation experiences and credentials of those teaching T&E education courses. As the data indicates, not all individuals are graduates of traditional T&E teacher preparation programs, nor are they certified to teach T&E education. For this reason, in-service as well as pre-service preparation efforts are critical for ensuring teachers receive the proper training to adequately teach STEM concepts. Additionally, the science coursework participants reported completing in this study was consistent with Strimel's (2013) research involving FoT teachers from multiple states (Love, in press). Both studies found that only about one quarter of FoT teachers had completed two or more courses in either physics, biology, or chemistry. Although the results cannot be generalized beyond the FoT teachers who participated in this research, similarities to the aforementioned national studies would lead one to expect similar T&E and science preparation experiences among a broader population of T&E educators.

Although teaching of science concepts is naturally embedded within T&E curricula and part of the STLs, this study is not suggesting that T&E educators be prepared to replace science educators. Rather it is simply suggesting the need for increases in select preparation experiences to better prepare T&E educators for making those interdisciplinary connections. As Wells (2008) suggests, the most viable solution for T&E educators to teach STEM concepts in an integrative fashion is to work collaboratively with science educators.

Implications and Recommendations

The findings from this study have implications for T&E education and science education. These implications lend themselves to providing recommendations for researchers, T&E educators, supervisors/administrators, and teacher educators.

Given the results from this research and the limited amount of T&E preparation that science educators have (Nadelson & Farmer, 2012), it implies that science educators would lack proficiency in teaching T&E content and practices. For this reason it is recommended that a replication study be conducted examining science educators' level of T&E PCK. The instruments from this study, specifically the TEES-PCK and modified RTOP, have implications to be used in future T&E and science education studies. The TEES-PCK provides a unique survey instrument that could be used by various disciplines to collect detailed data about formal and informal preparation experiences, while the RTOP is one of the first observation tools to help separately examine teaching of science and engineering content and practices mandated by the NGSS. It is recommended that researchers, especially within science education, utilize these instruments in future teacher preparation studies.

As determined by the Spearman's rho analyses and corroborated through the interviews, the greatest influence on teaching science content and practices was the amount of high school and undergraduate science courses completed. Therefore, T&E teacher preparation programs should advise students to take increased amounts of a variety of science courses at these levels. The relationship among graduate level science courses and teaching of science concepts warrants further research to investigate the rationale for this insignificant influence. Moreover, further research must also be conducted to examine the science PCK of teacher educators delivering T&E courses, and the emphasis they place on embedded science concepts.

In addition to coursework, meaningful informal preparation experiences (e.g., mentoring opportunities, time to collaborate with science and T&E teachers, curriculum training and resources, opportunities to deliver in-service sessions, professional conferences) should be supported by school systems and teacher preparation programs to increase T&E educators' proficiency in teaching science concepts.

There is still much work left to advance STEM-literacy in alignment with the STLs and the NGSS. One critical component for addressing this need is to ensure that T&E educators are adequately prepared for teaching embedded STEM concepts. Therefore, further research examining the preparation experiences of T&E educators is critical for informing teacher preparation efforts.

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