The Engineering Education Epistemology of a Science Teacher (RTP, Strand 1)

Katherine Levenick Shirey, University of Maryland, College Park

Katey Shirey graduated from the University of Virginia with bachelor's degrees in Physics and Sculpture. She received her master's in secondary science education, also from Virginia. After graduation, Katey spent five years teaching Physics at Washington-Lee High School in Arlington, VA during which she participated as a teacher liaison to the IceCube Neutrino Observatory at the South Pole. Katey is now a second-year graduate student in science education at the University of Maryland. Her current research interests are related to the ways that creativity relates to learning in physics instruction and how understanding creativity in the process of engineering design can inform physics instruction.

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Abstract

The Next Generation Science Standards[1] (NGSS) and an all-out push by President Obama and the Department of Education seek to reform science education by introducing engineering content and practices into Kindergarten through 12th-grade instruction. Science teachers across the grades are tasked with including engineering in their science curricula creating the need for research on NGSS execution and roadblocks. This qualitative study stemmed from an experienced high school physics teacher's unexpected change in co-planned engineering instruction during a math and science enrichment camp. In an attempt to understand Evan's* actions, this study examined the origins of and tensions within Evan's engineering education epistemology (EEE). My main research questions were, what are some identifiable features of Evan's education epistemology and engineering epistemology? How might these features combine in complex ways to form parts of his EEE? What tensions exist within his EEE? And how do tensions in his EEE affect his use of engineering in instruction? After triangulating Evan's explicit beliefs about engineering with his instructional practices, team conversations, an interview, and a member check**,** I assert that Evan's engineering epistemology involves reliable and efficient product creation but does he does not think engineers focus on learning new content knowledge as they create products. Evan's education epistemology involves providing opportunities for student success and teaching them new content knowledge. Together these epistemologies interact within his EEE. Evan abandoned engineering design projects for more traditional physics instruction at times when elements of his EEE conflicted. Understanding how Evan's EEE affected his use engineering instruction and his participation in NGSS reform efforts sheds critical light on the potential successes of the NGSS reform agenda in science classrooms.

Introduction

In the summer of 2014 I co-planned and co-taught an engineering-themed high school summer camp for science and math enrichment. My co-teacher Evan was a co-planner of this camp yet he made a sudden and covert shift away from our planned engineering activity on the third day of camp towards a more traditional mode of physics instruction. This paper explores Evan's utterances about instruction in camp and in his physics class in the hopes of better understanding how his beliefs about engineering education or his EEE informed his actions that day. The research questions for the qualitative study of this teacher were, **what are some identifiable features of Evan's education epistemology and engineering epistemology? How might these features combine in complex ways to form parts of his EEE? What tensions exist within his EEE? And how do tensions in his EEE affect his use of engineering in instruction?**

First, I review relevant literature on science teacher engineering reform and literature on the effects of science teacher epistemology on instructional choices. Then I describe my methods of data collection and dive deeply into my data set of teacher conversation and interview to seek Evan's priorities in engineering. Analysis of teacher planning and interview data revealed that seemingly-logistical aspects of lesson planning masked Evan's epistemologically-laden personal

*Pseudonyms are used throughout

values and experiences, which guided his engineering instruction decisions. Finally, I discuss implications for this type of research and reflection as science teachers take on engineering as recommended by the NGSS. This study suggests that identifying engineering epistemologies will be an important part of engineering integration in science classes; recognizing conflicts between teachers' priorities and the goals of reform curriculum could help to improve the frequency of teacher use of engineering.

Literature Review

In this literature review I build a rationale for my study by reviewing the purpose of adoption of engineering by science educators including the NGSS reform initiative background and its purposes; engineering education and the role of engineering design in the NGSS; and teacher reform implementation including science teacher preparation in engineering. Then I review research on teacher epistemology and teacher change to clarify my conceptual framework. I chose the literature here because of its immediate relevance to 9-12 science and engineering instruction, however much of the research on engineering education available is from the undergraduate and graduate levels of instruction. In this review I am not interested in reviewing the higher-education engineering literature because it mostly focuses on engineering instruction for engineering majors in engineering classes and therefore is quite different from "engineering for all" goals when taught by science teachers in K-12 science classes.

Rationale for Reform

The current national focus on science, technology, engineering and math (STEM) in education has created an apt moment for research on factors that can improve STEM instruction. In November 2009, President Barack Obama declared an "all-hands-on-deck" directive to improve STEM education in America[2]. This mandate came from the recognition that STEM fields are "highly-paid, highly-rewarding fields" (both personally and nationally) and that our students are now in the "middle of the pack" globally in STEM subjects (p.1). President Obama laid out a list of four priorities to improve STEM education including the recruitment of 100,000 new and effective STEM teachers, the closing of the achievement gap in STEM education, increased funding for STEM education, and inclusion of business and industry leaders in the educational reform movement.

The President's Council of Advisors on Science and Technology published the report *Prepare and Inspire* on STEM education in 2010[3]. PCAST noted the "tremendous challenges and historical opportunities" (p. 1) that our nation is facing and stated STEM education is "essential to our economic competitiveness and our national, health, and environmental security" (p. 2). In support of the need for improved STEM education, the report cited recent declines in STEM subjects as reported by the 2007 Trends in International Mathematics and Science Study (TIMMS), the 2006 Programme for International Student Assessment (PISA), and the National Assessment of Educational Progress (NAEP). In response to these meager results, and the potential usefulness of STEM careers, the President and PCAST mandated that STEM education must be improved to increase our global competitiveness. National educational attention and momentum is swung towards STEM learning in response.

The National Research Council published A Framework for K-12 Science Education in 2012[4]. In response to the call to education action in STEM, the framework included a novel push to include engineering throughout grade-banded standards including in practices, crosscutting concepts, and core ideas. This inclusion supported their primary goal:

> The overarching goal of our framework for K-12 science education is to ensure that by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (p. 1)

Engineering received a "prominent place" in the Framework[5] (p. *x*), and the mission of integrating engineering into science instruction from Kindergarten to 12th-grade began.

The NGSS reform initiative. The Next Generation Science Standards (NGSS)[1] expanded and operationalized The Framework by publishing discipline and grade level standards. In the NGSS "science and engineering are integrated … from kindergarten through twelfth grade" (p. 3). Although the NGSS is only adopted in 12 states and the District of Columbia as of December 8, 2014, the NGSS Lead States were careful to align the NGSS with the Common Core State Standards Initiative (CCSS) and to position the NGSS as the science companion to the CCSS which at the same time were adopted in 40 states. Currently, only state standards in reading and mathematics are compulsory, so adoption of the NGSS by a state is utterly optional.

The NGSS positioned K-12 engineering instruction within science disciplines at all levels following a rationale that "because engineering requires the application of mathematics and science through the development of technologies, it can provide a way to integrate the STEM disciplines meaningfully" [6] (p.2). Meaningful problems in engineering provide a practical context for acquiring new content, for motivating students, and for preparing them for the workplace[7].

What is engineering education? The discipline of engineering can be divided into engineering content and engineering design. Engineering content emerges from the intersection of science, mathematics, and necessity comprising a collection of tools, which engineers can use to design solutions to specific problems based on criteria and constraints. Rugarcia, Felder, Woods, and Stice[8] described engineering education as the development of engineering knowledge (facts and concepts), skills (design, computation, and analysis), and attitudes (values, concerns and preferences). Berland, Martin, Ko, Peacock, Rudolph and Golubski[9] drew attention to the dual goals of engineering in high schools: using engineering to deepen student understanding of math and science concepts, and teaching students the engineering design process.

While engineering content provides necessary tools to do engineering, it is engineering design, not content, that the Framework recognized as the "defining feature of engineering practice"[6] (p.2). Engineering design is the process of using iterative cycle of defining problems, gathering solution ideas, and systematically selecting, testing, optimizing and communicating solutions. Researchers stress that engineering design is not simply the application of science content[1,10]. Rather, engineering design is a particular problem-solving practice "involving a complex mixture of knowledge, process, and the enabling of skills or graduate attributes needed for professional practice"[6] (p. 2). While there are a variety of models describing engineering design in various contexts and sub-disciplines, engineering design always involves divergent practices (problem definition and design exploration) and convergent practices (design optimization and design communication)[11].

The emphasis on engineering design in the NGSS. The NGSS[6] prioritized student engagement in *engineering design* for grades K-12. Engineering design is present in all three branches of the NGSS: practices, crosscutting concepts and core ideas. Appendix I of the NGSS stipulates specifically that the NGSS defines engineering as “any engagement in a systematic practice of design to achieve solutions to particular human problems” (p. 103). The NGSS urges all students to practice engineering design to learn systematic problem solving, to “deepen [student] understanding of science by applying their developing knowledge to the solution of practical problems” (p. 3). Engineering design is “integrated throughout” the NGSS (p. 103): in the standards of all three disciplinary content areas, separate engineering design standards at all levels, and the eight Science and Engineering Practices. The Practices present a take on the design cycle that the NGSS advocates in Appendix I, one that involves the interplay of problem definition, developing solutions, and optimization.

Science teacher implementation of engineering. As states and schools phase in the NGSS, it will be current science teachers’ responsibility to teach engineering "...from kindergarten to twelfth grade”[1] (p. 103). The NGSS Lead States advocate that teachers should give the “core ideas of engineering and technology the same status as those in other major science disciplines” (p. 3). Appendix I specifically addresses the question of whether the engineering practices and concepts should suffice a new engineering class and concludes that the standards themselves “do not represent the full scope if such courses” (p. 107), instead engineering should suffuse all science classes on all levels. However, the NGSS “are not teaching methods or curriculum” (p. 50) and therefore, teachers, schools, districts, and states will be tasked with how to plan, teach, and assess the NGSS. The NGSS gives recommendations for instructional benchmarks and guidance for assessment but does not articulate curriculum, or activities.

Previous waves of reform suggest that in schools and school districts the teacher is the final arbiter of reform implementation[12]. Reform implementation and curriculum development groups are most productive when teachers’ collaboration is *situated* and acknowledges teachers’ own practice, experience, and culture and can articulate and debate their underlying disciplinary learning goals and associated epistemological assumptions[13]. Teachers’ shared values and visions are significant indicators of working-group success[14].

Science teacher preparation in engineering. Even for experienced science teachers, the inclusion of engineering could be potentially difficult as the vast majority lack formal engineering instruction[7]. Banilower, Smith, Weiss, Malzahn, Campbell and Weis[15] found only 7% of high school science teachers report feeling “very well prepared” to teach engineering (p. 26). This could easily be attributed to what the NGSS Lead States[1] call a “scarcity of teachers with training in engineering” (p. 3). Indeed, Boesdorfer and Greenhalgh[16] found only 10% of non-physics science teachers have taken an engineering course.

Research has shown that teacher preparation has an effect on student outcomes. Monk[17] found a positive relationship between math and science teachers’ coursework preparation and student outcomes though the absolute magnitude of the effect varied. Monk also found that pedagogical coursework had a more positive effect than content courses. Campbell, Nishio, Smith, Clark, Conant, Rust, DePiper, Frank, Griffin, and Choi[18] found that math teachers’ knowledge (TK) comprising of pedagogical content knowledge (PCK) and content knowledge (CK) positively affected student achievement outcomes, and that PCK and CK were related.

Teacher preparation affects student outcomes, but does preparation have an effect on teacher use of reform?

Teachers' lack of expertise in a content area can negatively impact the use of new content recommendations in the classroom. From a content perspective, research cautions us that although a superficial understanding of the design process may be acquired rapidly such as reading or memorizing a list of practices, experience using the design phases in isolation and in completion is necessary to master the process. As Dorst[19] stated, "…it only takes an afternoon to explain one of the design process models to a group of design students. But knowing that model doesn't make these students designers" (p. 5). This means that teachers learning about design quickly and superficially might not be enough to master the process such as to teach it. Only through extensive use and study can teachers and students learn the design process.

Teacher CK and PCK affect the use of reform, but so do teacher beliefs, attitudes, and prior experiences. In the following section I identify how all of these pieces combine to inhabit a teacher's epistemology of any given context.

Epistemology and Teacher Change

Chandler et al.[7] said that an *epistemology* is a way of reasoning and understanding the things we encounter in the world. Drawing from Aristotle they content that epistemologies are developed from formal and informal knowledge, lived experiences and assumptions about education as well as training and practice. They encompassed so much in epistemologies of specific subjects that regarding those specific epistemologies they said, "certainly we all bring all of our experience to the tale all of the time" (p. 42).

Hammer and Elby[20] defined student epistemologies as "category[ies] of informal knowledge that may play a role in students' knowledge, reasoning, study strategies and participation" (p. 1). Science teachers' epistemologies are a kind of knowledge then too, and will play a role in teachers' knowledge, reasoning, values, strategies and participation[21]. In K-12 education, teachers' lived experiences of a subject or phenomenon create a personal, informal familiarity. If science teachers are going to take on the topic of engineering in general, and by doing so participate in the NGSS reform, then their engineering epistemologies will affect their participation in the reform effort.

In my conceptual framework I adopt a "knowledge-in-pieces" view of epistemological frames similar to that of Elby and Hammer[22]. This view assumed that a person could have multiple epistemologies that pertain to various entities and that these may exist separately or in conjunction with others. Their chapter claimed, "A particular epistemological resource, we argue, can play different roles in different frames, and this feature of our framework has instructional implications" (p. 409). I acknowledge that this use of the word "epistemology" is troublesome for some, but in this case I find it to be the most useful way to express the notions of what an individual believes is the root of knowledge of a discipline and thus what they value, take up, and ignore. A simplifying statement might be, an epistemology is how one knows what they know about something specific, but perhaps, what one believes they know about something specific, is also apt. To be clear, I am not stating that Evan's epistemologies agree with the canonical version of what knowledge is in engineering or in education, what some might call the true, discipline epistemology. In this case I am identifying what Evan believes is at the root of engineering through his own words and allowing that vision to inform my analysis.

Education epistemology. Everyone has an education epistemology made up of experiences, formal and informal instruction, and assumptions about education. In America, nearly everyone has lived education experiences, from being a student in lower school, higher education, as a parent, as a home schooled individual, from church, or as a school community member. Even if one had not attended school, informal knowledge about school can come from hearing statistics about education in America in the news, seeing representations of classrooms on television shows, or feeling the inclusion or exclusion of school policies. Sometimes the purposes of school and individual pieces of instruction are explicitly taught, but more often, people make assumptions about the priorities of school officials and politicians, fellow students and teachers as well as assumptions about the purposes of school and the motivations for compulsory attendance.

The inputs to a teacher's education epistemology are more complex and formal than the average citizen. Often, teachers have had formal instruction on education through a teacher preparation course or professional development (PD). They are privy to the purposes of school initiatives and agendas through training, mandate, and evaluation. They also have more extensive lived experiences in schools as teachers. These experiences *as teachers* also impact their education epistemology. Teachers have an education epistemology consisting of their beliefs and values of what should be taught and how. Their education epistemology informs their practice, instructional methods, and use of various curricula in instruction.

Engineering epistemology. Everyone also has an engineering epistemology, similarly derived from lived experiences, formal and informal knowledge, and assumptions. Formal knowledge may be from classes taken in engineering or a definition of engineering; informal knowledge may be recruited from knowing an engineer or the use of the word "engineer" in the common vernacular; lived experiences may include experiences as an engineer in profession or when fixing, planning, or systematically solving a problem; and assumptions about engineering may come from hearing what an engineer's starting salary is, knowing that there are special engineering courses or schools, knowing that engineers build bridges, or knowing that NASA employs many engineers. Implications about what engineering is might impact how one values engineering, who aspires to become an engineer, or how one sees themselves as capable of doing engineering. Widespread misunderstandings of what engineering is and what engineers do may discourage women and ethnic minorities form engineering.[23] When teachers lack additional training in engineering it is likely that their engineering epistemologies are similar to that of the average American.

Engineering education epistemology (EEE). When teachers think about what to teach and how to teach engineering, their education epistemology and engineering epistemology must merge to create an engineering education epistemology (EEE). How the combination of engineering epistemology and education epistemology combine is not well researched. Chandler et al.[7] reported that even the paper called *Engineering in K-12 Education* released by the National Academy of Engineering and the National Research Council[23] acknowledged there is likely to be a conceptual disconnect between teachers' perceptions and teaching of engineering in K-12 classrooms and the accepted disciplinary and epistemic norms of engineering education. Theoretically, teachers' epistemologies could combine neatly and support each other to a clear, well-refined set of beliefs about teaching engineering. But it is also possible that a teacher's education epistemology might conflict with his or her engineering epistemology. At times a teachers' engineering epistemology may win out over their beliefs about education and how education should go, or vice versa.

While the connection between high school science teacher epistemologies and instructional choices has been explored in research, the relative newness of engineering in the high school science classroom means that there is little evidence on the transfer of EEE to practice in high school engineering instruction.[7] I hypothesize EEE will surely have an effect on practice as all epistemology does, and this study attempts to unpack that impact through qualitative analysis. I do not pretend to know the full interplay of these epistemologies, here I only surmise that my research subject, Evan, must hold some EEE that guides his decisions and I attempt to understand it better in light of his actions and words. This study attempts to identify elements of just one teacher's EEE in pursuit of understanding how his instruction links to his EEE.

Teacher change. Research shows that teachers' epistemologies affect how they incorporate reform agendas into their instruction. When teachers are offered PD through learning objects and repositories, they are likely to be perceived and used in ways reflective of their current practices[13]. Providing subject matter materials via websites or textbooks "do little to help teachers develop an understanding of the epistemology and pedagogy intended by the new curriculum" (p. 79).

Effects of reform-type initiatives on teacher change. Teacher implementers construct ideas about reform from policy, which influence what they do and do not do when implementing the reform[12]. Desimone, Phillips and Smith[24] investigated the implementation of reform proposals such as science standards through a constant comparative methodology. The authors investigated authority (persuasiveness of a policy), power (rewards and sanctions tied to a policy), consistency (a policy's alignment to a school system's elements), and stability (how stable actors and ideas in the policy environment are) to determine which factors influenced teachers' PD participation more. They found that authority is more associated with teacher engagement in effective PD around new policies than power is, and that stability, not consistency with other reforms, is associated with teacher engagement in PD.

Research on the implementation of previous reforms for more intellectually demanding K-12 science curriculum stemming from *Science for all Americans,* published in 1989, and the National Science Foundation's State and Urban Systemic Initiatives showed that teachers who were not given explicit support and training in the new standards were less likely to implement the reform.[12]

Current engineering reform efforts and teacher change. Chandler, Fonenot, and Tate[7] researched issues associated with the integration of engineering into K-12 instruction as well as other science reform efforts. They found that precollege engineering in STEM reform to be "especially problematic" (p. 40) due to a lack of traditional K-12 engineering curriculum. They continue by explaining that the epistemology of engineering education has not evolved to specifically inform the exigencies of K-12 education" (p. 40). It is to this lack of epistemic foundation, as well as a lack of standards (the article was published two years before NGSS) that the authors attribute "significant gaps in experience and knowledge to inform implementation" (p. 40). Although the NGSS now offers standards and practices for engineering education in K-12 science, there is still a lack of pervasive epistemic agreement.

Conceptual framework. Research has shown that what science teachers believe about science, their epistemology of science, influences the specific lessons that they plan[25]. To combine engineering and science curriculum, teachers will be inherently influenced by their fundamental epistemologies of what counts as learning and teaching in engineering; their engineering and education epistemologies. I connect these two with the phrase *engineering education epistemology (EEE).* Teachers will draw upon their personal experiences and understandings of engineering as well as resources (such as the NGSS) to plan and teach engineering. However, teachers' EEE might disagree with the foci and purposes for engineering education that the NGSS advocates. If disagreement between reform and a teacher's values occurs, then teacher change research indicates that buy-in and use of reform in instruction would be reduced[24].

My conceptual framework (figure 1) attempts to capture the connections between some influences impacting a teacher's EEE and the reform that may affect teacher decisions. The model comes from an adaptation of the structure-cultural-agency conceptual framework[26] using only the structure and agency arms, and Desimone, Smith and Phillips'[27] conceptual framework for the effects of PD on teachers and students. In my framework, a teachers' EEE, their knowledge about what engineering education is and what engineering instruction should be like, is influenced by their education epistemology and engineering epistemology, the lived experiences of engineering and education (such as a familiarity with the word "engineering" in common vernacular or knowing someone who is an engineer), formal and informal learning about engineering and education, and assumptions about engineering and education. In this model the EEE is also influenced by reform initiatives such as the NGSS. A teacher's decisions including participation, priorities, and instructional methods are all tethered to their individual EEE.

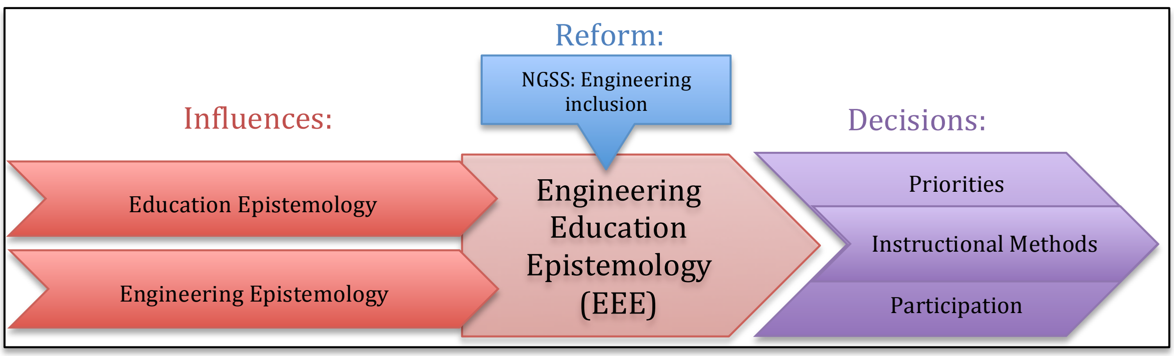

Fig. 1 My Engineering Education Epistemologies conceptual framework

Methods

In the present study, I tried to identify elements of a teachers' engineering epistemology, education epistemology, and EEE. I then tried to explore the tensions within his EEE and their instructional outcomes. In this section I will describe the research setting that allowed me to access my research subject, the evolution of my research questions, the methods of analysis, and the limitations of my study.

Research Setting

A nine-day summer science and math enrichment camp for 26 "at-risk" rising 9th through 12th graders occurred in July of 2014 in a suburban college-town outside of a large Midwest metropolis. The camp is for math and science enrichment but in 2014 it was decided by the teachers that the camp would have an engineering theme. I co-planned and co-taught the camp with a small team of five teachers, three of us returning, and two new to the camp. I was returning for my sixth year to the camp. Ricardo, an astronomy teacher in a community college in Puerto Rico, was visiting as a first-time co-teacher through a separate research project. Felicity was an education graduate student who was co-teaching the camp for the first time to earn a science education internship credit. Jess, then a six-year veteran math teacher and former engineer, was returning to camp for the third time. The fourth teacher was Evan, a 28-year veteran science (mostly physics) teacher returning to this camp for the 12th year.

The present research study is of this last teacher, Evan, and his personal priorities as he integrates engineering into science instruction at summer camp and in his high school classroom (evidence for this integration taken solely from his statements, not actual classroom observation). For full disclosure, I want to state that Evan and I are friends; we text and call each other throughout the school year, we know each other's spouses, I am good friends with his daughter, and we have co-planned and executed three PDs for teachers outside of camp. My role with him is friend, co-teacher, and researcher. We three have a mutually trusting and respectful relationship.

Research Questions

The research questions I'm asking about this experienced teacher are:

1. What are some identifiable features of Evan's education epistemology and engineering epistemology?
2. How might these features combine in complex ways to form parts of his EEE?
3. What tensions exist within his EEE? and
4. How do tensions in his EEE affect his use of engineering in instruction?

One specific moment at camp brought me to this research: Evan changed plans during camp by inserting a traditional physics optics bench lab into a telescope design challenge. Evan uncharacteristically changed instructional course away from our co-planned instruction, and I wondered why. This study delves into the clues from observation and interview of Evan understand why he strayed from our engineering design instruction to return to a more traditional physics lesson.

Data Collection

Audio, video, and photographic was collected for nine days of camp. Four co-teachers and 14 students consented to being audio-taped, video-taped, photographed, and interviewed informally. Further formal interviews with the teachers were also conducted after initial analysis. Throughout the camp I kept a running log of notes on the actions of the teachers, the ways the plans changed, and the data collected. In this study the teachers' discussion after the first day of camp was analyzed.

The audio and video data of the teachers' post-first-day planning session (50 minutes) was transcribed using InqScribe and transcriptions were loaded into NVivo, a qualitative analysis software. The transcript of the planning session was coded first for descriptive codes on the content of the discussion, and in successive rounds of coding analytically for evidence of engineering priorities, engineering and education epistemologies, and conflicts between identified epistemological elements. To augment the analysis I presented data twice to the Engineering Education Research Group and once to the Physics Education Research Group at The University of Maryland. The themes discussed below were in part developed from those meetings, which helped to mitigate the biasing potential of my own emotions and memories. Based on the initial video analysis, I developed tentative conclusions about what was going on among the teachers. I conducted a follow-up interview after about two month of examining the video data to put my interpretations to the test. The interview was semi-structured, but with a direct check about my initial conclusion. Evan's interview was also transcribed and coded which led me to return to the original data set and seek evidence to support my developing claim. Finally, after final analysis, a member check was conducted to ensure that Evan was comfortable with my analysis.

Limitations. Although I attempted to act ethically as an unbiased researcher throughout this research process, I would still like to clarify any potential errors that may have occurred. First and foremost, I acknowledge that my participation in the group and in the video analyzed could obscure my analysis. Though I attempted to "observe" the teachers' fifty-minute planning session post hoc, from video, allowing me to step away somewhat from the context of my feelings and motivations during the session, I recognize that this observation is limited by the influence of having been a participant and having had feelings that I remember from throughout the session. Another limitation to this study is that I feel challenged to ignore the insights that I have about the teachers throughout the summary; I am constantly aware that for me, there is more than meets the eye in the recording of the session, but my attention to details and conclusions should not be influenced by my personal understandings of those involved. I only hope to represent my research subjects well and appreciate the chance to learn about teaching engineering from their participation.

Findings

This section details my findings on Evan's engineering epistemology, education epistemology and EEE as well as influences on his engineering instruction. I found that Evan's engineering epistemology included a belief that the purpose of engineering is to make efficient and reliable products, and that he believed engineers create products without necessarily attending to or learning new science content. I drew this sentiment out of Evan's comments about what engineers do. I also found that Evan's education epistemology included a belief students should know why and how things work physically and that education should help students achieve success. I believe Evan's EEE is some shifting combination of these, and when his engineering epistemology seemed to be unsupported within his EEE, he reverted to his educational epistemology.

Evan's Engineering Epistemology

To address the first research question, what are some identifiable features of Evan's education epistemology and engineering epistemology?, I explored evidence of Evan's prior understandings of and values about engineering. Elements of Evan's engineering epistemology emerged through careful examination of his descriptions of what engineers do, and what well-engineered products are. In the following sections I highlight two pieces of his engineering epistemology: engineering creates efficient and reliable products and engineers can make these products without careful attention to understanding the physical foundation of the products or learning new content.

Efficient products. Evan communicated that engineering produces efficient products, products that can get as much done as possible while conserving time, resources and energy. In the interview Evan said, "an engineer makes a tool that can do things that allow you to be more efficient, and then allow you to focus on other things that you want to do at the same time" (lines 73-74). He emphasized two examples of efficient tools he uses in the classroom: the scoopula and the Vernier temperature probe. A scoopula is a thin metal trough with a point at one end, about the size of a pen. In contrast to a spoon, he said that scoopulas "do let you measure stuff really, really, you know, without wasting stuff" (lines 128-129). And again in the interview, Evan explained that a Vernier Temperature Probe, a metal stir stick that also takes digital temperature data, was a well-made, dual-purpose, efficient tool that he would select as a teacher-engineer over an old-fashioned glass thermometer and separate stir rod:

> 62 E: So that is a teacher-engineering thing. Where you have to look at
> 63 the problem, but what you're trying to do is you're trying to come up with the right
> 64 tool to use rather than analyzing the say, I just really want to record the
> 65 temperature of this, and so you could use a thermometer and then you can hold the
> 66 dang thing out and you could get a stirring rod and do it all over again and do the
> 67 stirring *but it doesn't allow you to do the two things twice, and that's what*
> *68 engineers do is they try and find a tool or um, that they can use* rather than just
> 69 relying on saying, hey, I want to be able to um, collect this data and for scientists the
> 70 data is the whole thing. So a thermometer takes precedence over everything that's
> 71 our, that's our tool of choice.
> 72 I: mm
> 73 Evan: *But an engineer makes a tool that can do things that allow you to be more efficient*
> *74 and then also allow you to focus on other things that you want to do at the same*
> *75 time*. [line numbers and italics added].

From these statements, I deduced that Evan valued tools that work efficiently (measuring without wasting) and are efficient (stirring and measuring at once).

Reliable products. It also emerged that Evan values reliability in engineered tools and products. Evan's intonation increased as he explained the advantage of the Vernier probe over a glass thermometer. He nearly shouted, "Because they're robust!" (line 55) when I asked him why he would prefer the metal probe. Likewise, he stressed the importance of a tool's "repeatability" (line 84) and the engineer's goal of building "something that works consistently well" (line 87) "so that people can use it on a regular basis" (line 106). Finally, Evan described a system he engineered for erecting a level tent on uneven surfaces. He explained that the best part of the new system is that it would work on terrain with any slope, at any kind of wind speed, indicating that he was proud that the system he devised was reliable. He described, "If your thing isn't level then you have to shim everything. But most of the time you're only out maybe two to three degrees, and so this allows me to get up to seven degrees of schwoop---y---ness" (lines 257-259) and "the day before we had 40 mile an hour winds, everything worked perfect" (lines 282-283).

In instruction, Evan stressed how he would like students to use a lab notebook to practice making repeatable designs, indicating that he does not value a design that only works once.

> 410 E: And you have to assume that the person that gave you the design knew what the
> 411 heck they were doing and understood how to make this so that when you go to use
> 412 their plan that it's going, going to work.
> 413 K: Yeah
> 414 J: Yeah
> 415 [00:32:22.14]
> 416 E: That------ that's that's the level I mean, that's the level of expertise that we didn't
> 417 have today. You know, we put stuff together and learned some things through each
> 418 iteration, but they really didn't, I mean, when we talked about writing stuff down
> 419 and those sort of things we we, I, we just seeing what they would write down is
> 420 important, and most of what they wrote down they could never repeat. Nobody
> 421 could repeat from what they wrote down. If you're going to hand something off to
> 422 somebody else tomorrow, you better be pretty darn sure that the plan that you give
> 423 them is going to work.

For Evan, a well-engineered product should work no matter who builds it. The product must be stable, reliable, and reproducible. These preferences are part of his engineering epistemology—to teach and learn engineering, efficient and reliable products must be an outcome.

At camp, Evan's preference for making reliable and efficient products also emerged with his frustration over the first day's outcomes. On the first day students built newspaper and spaghetti towers but Evan thought they weren't really learning engineering well because they weren't building efficient, destruction-tested towers. During the post-day conversation he said, "When you look at the learning stuff, nearly every one of them had string and tape left over. OK?" (lines 35-36) revealing his dissatisfaction with wasted materials through his frustrated tone. Evan advocated for a priority on efficient, reliable products by saying if students "had started having to decide where to put that tape on those things they would have found that they could use less material and made things much bigger and much lar—wider stuff and they could have used the string to support the –as these things started to bow out" (lines 83-85).

Engineers don't necessarily worry about why it works. Evan believes that engineers often create efficient and reliable tools without worrying about why or how they function. In the interview, Evan expressed dismay that his son's engineering school peers didn't want to be creative or think about "where the math and science stuff come together" (lines 369-370). They were "problematic" because they "were there simply because they wanted to know the process, they wanted to know how to make stuff so they could make money" (lines 366-367). "They were there to get jobs in engineering and they didn't care what kind of job it was, they just wanted to have the skill set to get employed" (lines371-373). The skill set he refers to here is his vision of what engineers do as they engineer, which may or may not have been his vision of the engineering design process the NGSS advocates for. For clarification I asked him, "kids just wanted to go from A to B, you called that a 'process' so that would be like kind of lock-step, like, then we do blah, then blah, blah. And Sam was like, No, let's look holistically and see a big picture and work on it. Is that close to what you were saying?" He replied simply, "yes". I confirmed again, "Make sure I got it right." "Yes" was his reply again. In summary, Evan's engineering epistemology centers on what he thinks engineers do. He thinks they create efficient and reliable products and do not always focus on learning outcomes rather they focus on product outcomes possibly made by step-wise procedures.

Evan's Education Epistemology

Evan's engineering epistemology was evident in his discussion of what engineers do. But another aspect of Evan's EEE is his education epistemology. Continuing with the first research question, I next searched out elements of Evan's education epistemology. In the following sections I describe two found aspects of Evan's educational epistemology: students should complete tasks successfully and students should learn science and math content.

Success. Evan believes students should feel success in completing activities. In subtle and obvious descriptions of his own teaching, Evan revealed how important student success is to him. He stated that his intention is to "improve the likelihood of success" (line 608). He continued, "That's all I want, all I want is so that when they get to the next level her as we move on that when they run into a frustration level with the Arduinos or whatever we're using, that they don't simply say, Well. It can't be done" (lines 618-620). In the six years that I've worked with Evan at camp I've known him to be an enthusiastic motivator and constant source of positive feedback in the classroom. Evan made statements in the interview that implied his intent that students achieve success such as, "you have to figure out what allows you to let kids um, have opportunities that they wouldn't normally have before" (lines 91-93) and "you're always trying to figure out a way to make it work… so that they don't hurt themselves, and so that they get the outcome hat they want" (lines 96-100). Evan believed at least one purpose of education, and one piece of his education epistemology, is that education should help students achieve success, at times new, and at times difficult.

Content acquisition. In addition to achieving success, Evan hoped that through his instruction students would learn science and math content knowledge, not just do certain actions or perform well on tests. “Number one is that they can’t just rely on their past experiences” (lines 608-609). He emphasized “the learning stuff” (line 35) in the staff meeting and also explained his frustration that students might not have learned about lenses through a telescope engineering activity we planned. Regarding the activity he said, “we're spending a whole lot of time for that one thing to learn some basic background stuff but when it comes to the materials part of this stuff [the optical instrument task], we're just saying, you really don't need to know that to build these things!” (lines 363-366). Evan hoped that his instruction would teach new content knowledge and was not satisfied that any teaching wouldn’t involve new knowledge acquisition.

The following chart (Figure 2) attempts to summarize my analysis so far: Evan’s engineering epistemology is at least in part that engineers create efficient and reliable products, and that they don’t always need content knowledge to do so. His educational epistemology is at least in part that students should find success and learn content knowledge.

Evan’s Engineering Epistemology	Evan’s Educational Epistemology
• Engineers make efficient products. • Engineers make reliable products. • Engineers use a process that doesn’t always involve content acquisition.	• Instruction should lead students to success. • Instruction should lead students to learn content knowledge.

Figure 2. Identified components of Evan’s engineering epistemology and educational epistemology

Evan’s EEE and Conflicts Within

To address the second research question (how might these combine in complex ways to become his EEE?) I attempted to first draw Evan’s engineering and education epistemologies together into an EEE. My perceptual framework claimed that Evan’s EEE is a negotiation of his engineering epistemology and his education epistemology, however, I first attempted a naïve combination of the sets and listed the possible elements of Evan’s EEE that emerged: engineering instruction should lead students to make reliable products and efficient products; engineering instruction should lead students to success; engineering instruction should lead students to learn content knowledge; and engineering instruction should lead students to use a process, which doesn’t always involve content acquisition. Please see Figure 3 for a representation of how Evan’s engineering epistemology and education epistemology combined to form a naïve view of his EEE.

Evan’s Engineering Epistemology	Evan’s Educational Epistemology
• Engineers make efficient products. • Engineers make reliable products. • Engineers use a process that doesn’t always involve content acquisition.	• Instruction should lead students to success in project completion. • Instruction should lead students to learn content knowledge.
Evan’s EEE	

- Engineering instruction should lead students to success.
- Engineering instruction should lead students to learn content knowledge (physical and mathematical).
- Engineering instruction should lead students to make efficient products.
- Engineering instruction should lead students to make reliable products.
- Engineering instruction should lead students to use a process, which doesn’t always involve content acquisition.

Figure 3. Evan’s combined EEE

To address the third and fourth research questions, what tensions exist within his EEE? And, how do tensions in his EEE affect his use of engineering in instruction?, I searched for places where Evan’s EEE had internal tensions and the outcomes of these tensions. Two conflicts emerged as I investigated Evan’s EEE. The first was evident in an example where students were doing an engineering project with engineering steps, but they did not complete an efficient and reliable product. The second was evident in an example where students did an engineering process without learning new content. In the next sections I will explore these two conflicts.

Conflict between doing engineering processes and creating robust products. Evan’s EEE included the idea that student success in an engineering project should yield efficient and reliable products. For Evan, is not adequate that engineering instruction simply teach about engineering design without creating a final robust object. Evidence for this claim includes two engineering activities that Evan engaged students in but when neither one yielded a functional product Evan abandoned both projects. The first was a Kinex roller coaster project and the second was a catapult project.

During the camp staff discussion, Evan recalled an engineering construction project that he attempted without success for five consecutive years in his physics classroom. He asked students to make parts of a large Kinex roller coaster and to fit them together. In slow, paced tones, and a weary voice Evan described how the project failed five years in a row because a reliable product was not built. Here’s his description of what happened:

E: I’ve had my students’ take and make each page that's what they're responsible for and then they have to take that piece and they have to connect it to the next piece to the next piece and guess what?
F: They don't line up?
E: They do not line up. They do not line up. Because they in-- invariably have problems with attaching the materials, they put a truss member in wrong or they use a wrong piece, and so the dimensions are off just a fraction of an inch. And so the only way that you can actually build them is to build it from start to finish.

For Evan, the fact that the Kinex parts did not line up to make a successful outcome meant the project was a failure even though the students worked through the project as they were instructed. Year after year he hoped for a different outcome but never found success in a reliable product. After the fifth try he gave up and stopped doing the project in class. He ceased the inclusion of an engineering project although student may have been learning about engineering design because the students did not make robust roller coasters. The realities of the classroom created a tension between his engineering and education epistemologies.

In his interview, Evan described a second project where this tension was also apparent. Evan had students design catapults from cardboard. The students worked to design the catapults, but were ultimately stymied by a lack of experience with cutting the cardboard and they couldn’t make a robust product, even though they spent much time engineering. Evan explained, “they hated it, they hated it. No, they didn’t hate it, the fact that it was so much harder than they ever expected it was gonna be… that made ‘em really upset… so we ended up, we ended up stopping” (lines 172-177). Here Evan recalled that the students conducted an engineering design challenge, but the project was abandoned because finishing the final product was too difficult for the students. Again, conflict within his EEE, that between learning design and creating products, caused him to abandon the engineering instruction.

Content versus process conflict. Evan’s EEE contains another conflict, that between doing engineering to learn the design process and doing engineering to learn content knowledge. In several examples I found that Evan’s educational epistemology that students must learn new content consistently beat out his engineering epistemology that engineers design without learning new content. In two examples, Evan’s displeasure with engineering spaghetti towers for the sake of learning engineering design and his switch from a telescope project to an optics lab, Evan felt tension between students learning content knowledge and students learning about engineering design.

Evan critiqued our camp’s first day project, building spaghetti towers to better understand constraints, criteria, and iteration. Evan advocated for an increased emphasis on materials exploration (content acquisition) to learn about stress, strain, and structural members such as spaghetti and tape. In the following passage, Evan suggested that the outcome would have more successful, and better-engineered if the students had learned more about the materials and their physical properties, not just the process of design.

> E: So, they didn't learn a lot about string, or they didn't learn a lot about tape. Ok?
> Because a lot of these things would been a lot taller, from an engineering
> perspective [gestures to Jess], had they used a little bit of tape as a structural
> member in order to increase the strength and the dynamic strain on some of these
> things. All’s you had to do is put a piece of tape [gestures] where you’re under
> tension, and everything becomes, um, much easier to deal with.

Evan made the claim that the lesson would have been better if the instructions had included exploring the physical properties of the materials. In this passage Evan spoke emphatically, with several instances of raised voice for emphasis on the requirements he would have liked. In this case, if exploring materials within a design challenge could help students gain content knowledge and achieve success as they completed a product then Evan would have been okay with it.

The content acquisition conflict between Evan’s engineering epistemology and education epistemology came to a head with the telescope project at camp. Evan drew a contrast between a traditional optics lab where, according to his education epistemology, success would be learning optical content knowledge and designing an optical instrument like a telescope, which according to his engineering epistemology would not require learning new content. “Optics bench is different than constructing something that they can walk away with” (lines 258-259). “One is learning about flipping something over [an optical inverse image] and the other is actually constructing the device. See what I’m saying?” (line 262).

In the planning meeting Evan hoped that students would do both. “We’re looking at the what, how lens and mirror works so that we can take those to create a product” (lines 478-479). But in the moments before the telescope project was about to begin, Evan made a sudden shift from framing the optical investigation as an engineering project to instead being a traditional optics lab where students were investigating physical phenomena and not engineering a product. The product was never mentioned during the three hours that the lab was executed.

Here Evan's education epistemology was threatened—perhaps he thought students would not learn the optics content that he knew they would learn with a traditional optics bench lab. His years of experience with the optics bench lab won out, and he insisted the students learn the content in a way he could be sure of. For him, simply engineering the telescope would not necessarily teach the content, after all, engineers don't always need content to engineer a product. This decision belied his very real concern that students wouldn't learn content (upsetting his education epistemology) even though they were doing an engineering activity. Within his EEE the engineering epistemology took a back seat as his education epistemology took over.

Discussion

The conceptual framework in Figure 1 describes how Evan's instructional decisions stem from his EEE—what he thinks engineering instruction should be. Evan's EEE is a combination of his engineering epistemology and his education epistemology. His engineering epistemology includes a belief that engineering creates efficient and reliable products, but his education epistemology includes a belief that students should learn content through instruction. For him, the purpose of engineering in his instruction draws on his EEE, which is not a simple combination of this engineering epistemology and his education epistemology. There are conflicts among the individual parts that create tensions causing Evan to have to choose which elements will take priority in the moment. It seems that he hopes students will have the experience of finishing a useful product but prioritizes the belief that any instructional task, even engineering ones, must involve learning content knowledge.

From the examples of the Kinex roller coasters, the cardboard catapults, the spaghetti towers, and the optics bench intervention I conclude that conflict within Evan's EEE caused him to make instructional decisions that usually abandoned engineering in favor of traditional, content acquisition-oriented instruction. In the cases where a final, real product wasn't finished, and wasn't finish-able (such as the catapult or the Kinex after five years), Evan pulled the plug on the projects and spent his instructional time differently. In the cases where content acquisition wasn't occurring or guaranteed, Evan also put a stop to engineering design.

In the cases where content wasn't learned (such as the spaghetti tower), Evan criticized the project and advocated for increased emphasis on content. In the case of the telescope project, Evan's switch to a traditional lab instead of another design challenge was in reaction to what he saw as inefficient and amateur design products—something his engineering epistemology elements won't allow. So, his education epistemology took over and he switched course to conducting a "safe" lab that he knew students could be successfully learn content from. When his EEE is in conflict to the ways that "engineering" unfolded in his classroom, Evan tended to stop the engineering activity or revert to a more traditional type of content acquisition. It seems plausible that Evan's decisions to disengage from engineering as suggested by reform, including stopping the catapult design, ceasing the roller coaster project, and traditionalizing the optics bench lab these decisions were a direct reflection of his EEE tension.

From another lens, all of these attempts could be seen as successful engineering projects or successful physics instruction. In the frame of Berland et al.[9] teaching students the engineering design process through both the Kinex project and the catapult project might have been seen as an instructional success. In both cases, students worked to design a product and moved through various phases of design, modeling, and troubleshooting. However, the conflict with finishing a robust product within his EEE meant that he stopped the engineering instruction altogether.

The projects also may be viewed to support the engineering practices advocated for in the NGSS. In the spaghetti project students defined a problem (NGSS Practice 1), interpreted data (Practice 4), develop models (Practice 2) and attempted to complete a design solution. Though they were stymied in the final outcome, they could be viewed as efforts to learn about engineering design.

While these lenses might conclude that Evan's instruction is significant in that it teaches engineering design, it seems that Evan does not. Hence, Evan's EEE sits in contrast to other possible epistemologies of engineering education such as those embedded in the NGSS. For example, the NGSS squares its purpose on learning design for the benefits of problem solving and contextual motivation through practical and meaningful problem definition as well as allowing opportunities for creativity, and leaning from failure. Evan seems not to place overt emphasis on these elements in the data collected. Surely, this data set is not a large enough set to encompass all of Evan's engineering and education priorities or epistemologies, but from what data was examined, there seemed to be a trend that conflict between epistemologies that affected Evan's participation in the kind of design-based engineering reform advocated for in the NGSS.

Implications. An implication of this study is that when a teacher's EEE is not aligned with the epistemology of a reform effort such as the NGSS, then he or she will be less likely to participate in the effort. To alleviate such conflicts, and to get engineering into the American classrooms where the NGSS hopes to have it presented, the contrasts between teachers' EEE and the epistemology of the reform effort, its purposes, practices, and holistic gestalt, must be addressed specifically. Although this study did not investigate the best way to merge epistemological goals, some research on clashing epistemologies in teacher PD point to a need to confront any underlying disagreements in epistemologies so that at least the differences are apparent and the teacher doesn't choose not to participate[13].

Conclusion

Previous research has shown that science teachers' beliefs about science influence the specific lessons that they plan[3] even when standards promote other disciplinary benchmarks or practices. Evan's case shows that the same may be said for teachers' EEE. Conflicts within Evan's EEE and conflicts between his EEE and aspects of engineering education promoted by the NGSS led him to give up on engineering projects and to switch to more traditional modes of instruction.

In places where teachers plan science either alone or in groups, their instruction choices are situated in their individual practice, experience, culture, learning goals, and associated epistemological assumptions[13]. The study provided a peek into the EEE of one science teacher as he took on engineering. I concluded that even science teachers who do not teach engineering may have well-developed engineering education epistemologies that affect their choices in instruction. I argued that Evan's words and actions preliminarily support a claim that teachers' root ideas about what engineering is (their engineering epistemology) and their beliefs about education (their education epistemology) guide their engineering instruction through an EEE even when standards disagree, and even when a teacher is dedicated to implementing a reform initiative.

Evan has his own, unique perspective on engineering, which this paper attempted to identify and unpack. This study has attempted identified only a few of the elements of Evan's engineering and education epistemologies, which are surely more complex than I have given service to. My analysis of how his EEE is influenced by these may only relevant in the examples

I found through observation and interview, and I freely acknowledge that my analysis is imperfect and perhaps even affected by my personal friendship with the research subject and involvement in the research setting. However, I feel it is possible to view his EEE in contrast with NGSS's epistemologies, and to understand that such conflicts not only create struggles when planning, but that internal EEE conflicts could impede the inclusion of engineering into science classrooms.

Further engagement with this data might help to reveal what other participants' priorities are further fleshing out the range of engineering education epistemologies that exist in science teachers. Additional exploration on how teachers' epistemologies contrast and the effects on group planning and instruction would help to identify other considerations in the implementation of the NGSS reform effort. In exploring the data for implicit and explicit teacher conflicts, it might be possible to anticipate sticking points or conflicts for future implementation.

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