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Board 168: Exploring K-12 S,T,E,M Teachers' Views of Nature of Engineering Knowledge (Work-in-Progress)

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Abstract

Current K-12 science reform advocates for the interdisciplinary infusion of engineering within the context of collaboratively engaging learners in real-world problems. As such, K-12 science, technology, engineering, and math (STEM) teachers need adaptable conceptual and epistemic understandings of engineering as a set of discrete disciplinary knowledge, skills, and career paths. They should also understand engineering as a highly contextual, socially, and culturally bound, and solutions- and goal-based endeavor. However, research has repeatedly revealed gaps in teachers' understandings: the same reservoirs of knowledge teachers use to make instructional decisions in their classrooms. As such, attention is needed to explore and provide targeted support for teachers' epistemic understandings of engineering. If teachers cannot understand the nature, scope, or validity of engineering knowledge, they may not be able to portray or enact engineering with their learners authentically.

Using a mixed methods approach, this proposal seeks to identify and characterize K-12 S, T, E, and M teachers' ($\geq$ five years of STEM teaching) views of the nature of engineering knowledge. These teachers represent experienced practitioners in their fields who offer essential insights into learning how to support teachers' epistemological understandings. Participants included 23 elementary ($n = 7$), middle ($n = 7$), and high school ($n = 7$) S, T, E, and M teachers who were part of a university-school partnership geared towards developing and implementing a multi-day standards-based STEM task in their classrooms. Data included participants' responses to a previously validated Views of Nature of Engineering Knowledge (VNOEK) survey and researcher-developed STEM pre-survey.

The VNOEK comprises 13 open-ended prompts to examine and optimize a community-wide water filtration system. Data analysis consisted of independently coding and corroborating data using validated procedures with a focus on teachers' VNOEK, and teachers' responses were categorized as "Informed," "General," "Emergent," "Problematic," or "Absent." Preliminary findings revealed that: (i) participants held largely emergent but contextually responsive epistemic understandings and (ii) unearthed potential differences in these understandings when compared across teachers' grade bands and disciplines (e.g., S, T, E, or M). Additionally, teachers appeared to focus on the personal and community-based nature of the engineering problem, suggesting a clear entry point for bolstering their views. Findings indicate the need for additional exploration and comparison of teachers' VNOEK across contexts (e.g., grade levels; experience; discipline) and provide concrete directions for further engineering education research.

Introduction

Current K-12 science, technology, engineering, and math (STEM) reform advocates for the interdisciplinary infusion of engineering within the context of collaboratively engaging learners in real-world problems (NGSS Lead States, 2013; ISTE, 2017; ITEEA, 2020). As such, K-12 STEM teachers need adaptable conceptual and epistemic understandings of engineering as discrete disciplinary knowledge, skills, and career paths (Bryan & Guzey, 2020). Understanding engineering in this way means being able to recognize and articulate it as more than merely a sub-construct of science (Van den Bogaard et al., 2021), but rather a related yet distinct discipline with its own highly contextual and culturally bound practices, processes, and outcomes (Lewis, 2006; Pleasants, 2020).

Nevertheless, research has repeatedly revealed gaps in STEM teachers' understandings of engineering (Knight & Cunningham, 2004; Hsu et al., 2011): the same reservoirs of knowledge used to make related instructional decisions in their classrooms (Moss, 2019). As such, attention is needed to explore and provide targeted support for teachers' epistemic understandings of engineering. If teachers cannot understand the nature, scope, or validity of engineering knowledge, they may not be able to authentically portray or enact interdisciplinary engineering design-based science instruction with their learners (Radloff et al., 2019). Research has also shown significant variation in interdisciplinary STEM instruction across classrooms (Katehi et al., 2009; Dare et al., 2021). While this variance has been attributed to teachers' unique classroom adaptions (McFadden & Roehrig, 2019) and the nature of given STEM tasks (Radloff et al., 2019; Roehrig et al., 2021), more attention is needed to understand how teachers' epistemic views of engineering may also impact their resulting classroom enactment. This exploration should start with elucidating teachers' epistemic views about engineering.

Using a mixed methods approach, this study sought to identify and characterize experienced K-12 STEM teachers' ($\geq$ five years of STEM teaching) views of the nature of engineering knowledge (VNOEK). This context is unique, given participants' extensive teaching experience and wisdom of practice (Shulman & Wilson, 2004), and offers essential insights into learning how to support all teachers' epistemological understandings of engineering. As adapters of their pedagogy and instruction (Biggers & Forbes, 2013; Forbes & Davis, 2010), STEM teachers rely upon their classroom and content knowledge to enact novel reform (Craig et al., 2008; Forbes, 2013) that includes integrating engineering (NGSS Lead States, 2013). If we understand experienced teachers' VNOEK, we can potentially gain a deeper understanding of why they make resulting classroom decisions toward creating targeted professional development resources for all teachers. As such, the research question guiding this study was: *What are experienced STEM teachers' views of nature of engineering knowledge?*

Interdisciplinary STEM Instruction

We used Roehrig and colleagues' (2021) interdisciplinary STEM and Antink-Meyer and Brown's (2019) NOEK frameworks as a lens by which to examine teachers' VNOEK in this study. We use Roehrig's (2021) work to define and clarify our positioning of the teacher participants as STEM teachers familiar with using engineering design to teach their disciplines. We use Antink-Meyer and Brown's (2019) work as it was previously the catalyst for developing the validated VNOEK survey instrument (Antink-Meyer & Brown, 2020; Brown & Antink-Meyer) used in this study.

Roehrig (et al., 2021) define interdisciplinary STEM instruction as having core components: (a) engineering design as an integrator; (b) real-world problems; (c) purposeful context and content integration; (d) STEM practices; (e) 21st-century skills; and (f) STEM career emphases. Through an emphasis on using engineering design within the context of real-world STEM issues, this framework also highlights the iterative, collaborative, and open-ended nature of engineering (Lawson & Dorst, 2013; Stretch & Roehrig, 2021). It also centralizes the interdisciplinary connections between STEM subjects and underscores the importance of connecting to learners' lives (Antink-Meyer & Brown, 2019). These connections can be bolstered by engaging learners with real STEM issues, careers, and practices (Kitchen et al., 2018). STEM is not a single subject, but rather the integration of two or more disciplines (Bryan & Guzey, 2020). Likewise, it should not substitute for individual disciplines (NSTA, 2020).

Effective STEM instruction requires teachers to facilitate students' collaborative development and refine engineering design solutions (Hynes, 2012; Radloff et al., 2019). "Facilitation," in this context, means recognizing and supporting students' varying progress in design teams in real-time as they engage in the design process and leveraging students' diverse ideas and reasoning to make sense of their investigations (Capobianco et al., 2018). As such, teachers need adaptable understandings of STEM ideas and practices to respond to students' needs (Wendell et al., 2019). Teachers must also be able to evaluate, adapt, and adopt authentic and immersive experiences for their own classrooms (McFadden & Roehrig, 2019). This evaluation entails recognizing the components of an effective task and how teachers may adapt and integrate existing STEM lessons within their specific classroom contexts (Roehrig et al., 2021). We argue that all these practices require informed epistemic understandings of the underpinnings of engineering.

Nature of Engineering Knowledge (VNOEK)

Definitions of nature of engineering (NOE) developed for use in the interdisciplinary K-12 STEM classroom exist but are emergent (Karatas et al., 2011; Deniz et al., 2017; Pleasants & Olson, 2019; Pleasants, 2020). Despite the longstanding prevalence of nature of science (NOS) in national reform (Lederman & Lederman, 2014), authentic yet accessible classroom-based models of NOE are still needed. Antink-Meyer & Brown's (2019) NOEK framework was developed to address this need, wherein "NOEK" is defined here as "characteristics of engineering knowledge."

The NOEK framework comprises seven codependent features of engineering. These aspects delineate engineering as (i) interdisciplinary, (ii) contextually responsive, (iii) empirical, (iv) solution-oriented, (v) personal, (vi) societally and culturally relevant, and (vii) social. Engineering is *interdisciplinary* as it is co-dependently connected with and impacted by advancements in other STEM disciplines (Pleasants, 2020). It is *contextually responsive* in that it reflects the criteria and constraints of specific design challenges (Bryan & Guzey, 2020). It is *empirical* because it is evidence-based and relies upon modeling to gather and analyze performance data (Lewis et al., 2006). Moreover, it is *solution-oriented* in that the needs of humans drive it within the designed world (Capobianco et al., 2013).

Engineering is also *personal* in the way that it is a human endeavor. Engineers perform it based on their creativity, experiences, and perspectives (Johri & Olds, 2010). Furthermore, it is *societally and culturally relevant* as design problems and solutions arise from and change according to global shifts in cultures and communities (Dalvi et al., 2016). Lastly, engineering is also a *social* endeavor as engineers make design decisions and provide and receive feedback from their design teams (Bucciarelli, 2001).

While detailed, this list is not exhaustive but was developed by engineering experts and engineering education researchers to align with national STEM reform and K-12 standards-based classroom translation. As such, teachers' VNOEK can be considered their understanding of these engineering aspects. Given the potential wisdom of practice gained through continued implementation of engineering design within the classroom context (Capobianco et al., 2018; Hynes, 2012; Martin et al., 2015), the current study hypothesized that experienced STEM teachers would display informed VNOEK.

Context of the Study

The context of this study is a multi-year partnership between SUNY Cortland, the Office of Naval Research (ONR), the statewide Boards of Cooperative Educational Services (BOCES), and several elementary, middle, and high school STEM teachers across New York State. This initiative is aimed at improving: (i) pre- and in-service teachers' abilities to implement engineering design-based learning experiences and (ii) students' STEM achievement in pursuit of "Naval STEM" disciplines and careers. During the fall, participating teachers visit the Naval Undersea Warfare Center Division Newport (NUWC) and learn about related research from the researchers and then collaborate with peers, university STEM faculty, and Naval STEM experts (e.g., research scientists and engineers). They then develop original multi-day engineering design-based lessons for enactment in their classrooms over the following two semesters. Following their NUWC visit, teachers participate in ongoing professional learning workshops (i.e., fall and spring) where they learn to use the 7E model of STEM instruction (Eisenkraft, 2003) to guide their lesson planning and implementation and reflect on their lesson development with their peers. Aligned with our framework, engineering design-based instruction is at the core of this model. Teachers self-identify their Naval STEM lesson topics and form teams of 3-5 teachers (based on these interests) to develop their lessons. "Naval STEM" tasks are those contextualized using Naval research that include NUWC-based topics of (i) biomimicry, (ii) electromagnetic sensing, (iii) marine mammals, and (iv) unmanned undersea vehicles.

Participating teachers (n = 21) identified themselves as either male (30%) or female (70%) and White (89%), Hispanic/Latino (9%), or American Indian/Alaska Native (1%) with five or more years of STEM teaching experience (Table 1 below). They worked across New York State in suburban (43%), rural (38%), or urban (19%) school districts, identified by teachers as such based on proximity to city centers. They were equally distributed across elementary, middle, and high school levels of education (n = 7 teachers per grade band). Importantly, all teachers identified as "STEM teachers" who utilized interdisciplinary STEM instruction in their classrooms. Pseudonyms were assigned to all participants to maintain their anonymity and used throughout the results and analyses (including below in Table 1).

Table 1
Summary of teachers' self-identified demographics

Participant	Years in the Field	Grade Level(s)	Subject Area(s)	Location	Gender
Zander Neill	16-20 Years	K-2, 3-5	All subjects	Rural	Male
Mandy Morwall	21-25 Years	K-2	All subjects	Rural	Female
Pam Kronkite	6-10 Years	3-5	All subjects	Rural	Female
Bridget Hiddad	6-10 Years	3-5	All subjects	Rural	Female
Stacy Ardlow	21-25 Years	3-5	All subjects	Rural	Female
Lori Jeppson	16-20 Years	3-5	All subjects	Rural	Female
Brenda Carlo	16-20 Years	3-5	All subjects	Rural	Female
Lindsey Crandall	4-5 Years	6-8	Living Environment,	Urban	Female
Haddie Calhoun	11-15 Years	6-8	Life Science, Earth	Suburban	Female
Wendy Michaels	11-15 Years	6-8	Earth Science	Suburban	Female
Mikayla Little	4-5 Years	6-8	Earth Science	Urban	Female
Frank Jackson	25+ Years	6-8	Life Science & Living	Suburban	Male
Franny Daniels	25+ Years	6-8	Life Science, Physics,	Urban	Female
Jackie Tackler	11-15 Years	6-8	Earth science, Life	Suburban	Female
Paula Ringo	25+ Years	9-12	Living Environment	Rural	Female
Stuie Lucia	4-5 Years	9-12	Earth Science, Marine Biology, Environmental	Urban	Male
Louie Cross	16-20 Years	9-12	Math, Engineering	Suburban	Male
Eva Ashton	4-5 Years	9-12	Forensics and Chemistry	Suburban	Female
Harry Jones	25+ Years	9-12	Living Environment, Environmental Science,	Suburban	Male
Phil Ericson	16-20 Years	9-12	Earth Science	Suburban	Male
Mike Sanders	16-20 Years	9-12	Chemistry	Suburban	Male

Data Collection and Analysis VNOEK Questionnaire

Data included participants' responses to a previously validated Views of Nature of Engineering Knowledge (VNOEK) survey (Antink-Myer & Brown, 2020; Brown & Antink-Meyer, 2022). The VNOEK comprises 13 open-ended prompts centered on examining and optimizing a community-wide water filtration system and new concrete-type bridge-building material, accounting for specific criteria, constraints, and community needs. To be clear, these prompts are aligned with NOEK tenets described above (Antink-Meyer & Brown, 2019) but did not explicitly ask participants about NOEK tenets; they focused on clarifying what knowledge engineers would need to solve the scenarios and how they relate to engineering. The VNOEK survey has established validity for use with K-12 STEM teacher populations, and it was used in the current study to gather and compare experienced S, T, E, and M teachers' views. Participants' responses are rated based on the presence (or absence) of NOEK understandings and were annotated as follows: (1) Does not contain any defined NOEK knowledge, (2) Contains partial NOEK knowledge (but some misstatements), (3) Contains partial NOEK knowledge (no misstatements), (4) Contains somewhat correct NOEK knowledge (no misstatements), or (5) Desired NOEK understanding.

Data Analysis

Data analysis consisted of independently coding and corroborating data using validated procedures focused on teachers' VNOEK (Antink-Meyer & Brown, 2020). This qualitative portion of the analysis entailed coding teachers' responses to each VNOEK question and categorizing those together according to the NOEK framework. Rather than coding each response, participants' responses were coded holistically for the presence of engineering as contextual, empirical, social, solutions-oriented, personal/individual, and socially and culturally embedded. Aligned with the VNOEK ratings described above, teachers' responses were categorized as "*Informed* (5)," "*General* (4)," "*Emergent* (3)", "*Problematic* (2)," or "*Absent* (1)." The first and third authors coded the data independently and then met to corroborate codes (Miles et al., 2018). The third author is an experienced VNOEK scorer, and both scorers reached 100% interrater reliability (Creswell & Creswell, 2017). This data was then separated and compared quantitatively across teachers' grade levels (elementary, middle, high) and discipline taught (S, T, E, or M) using descriptive statistics (e.g., mean, media, and mode), and the results are described below.

Results

Findings revealed that participants held largely emergent but contextually responsive epistemic understandings. They also revealed potential differences in teachers' understandings when compared across teachers' location, subject area(s) taught, and years taught; within grade bands. Additionally, we found that teachers appeared to focus on the personal and community-based nature of the engineering problem, suggesting a clear entry point for bolstering their views.

VNOEK Scores

Teachers' VNOEK scores are summarized quantitatively below (in Table 2), followed by explanations and qualitative example quotes from each category (e.g., "Informed" vs. "Problematic"). Results are organized according to the variables of teachers' (i) grade band; (ii) years taught; (iii) subject area(s), and (iv) location. As this represents a work in progress, descriptive statistics (i.e., frequencies, averages, and standard deviations) were used to compare teachers' responses quantitatively.

Table 2

Teachers' VNOEK scores arranged alphabetically by pseudonym

Name	Years in the Field	Grade Level(s)	Subject Area(s)	Location	Engineering as: **Contextually responsive:** criteria and constraints; evolutions of design and design processes	**Empirical:** optimization is central; design is evidence based; modeling allows data gathering and feedback	**Solution-oriented:** motivated by human problems and desires for new and improved systems, processes, and artifacts	**Personal/ Individual:** reflects personal, professional, and academic experiences; unique solutions to identical problems	**Societal and Cultural:** affected by and effective of aesthetics, problems, and expectations of communities	**Social:** often team-based; develops through client, peer, and colleague feedback and insight	**Interdisciplinary:** science, technology, and engineering co-develop
Brenda Carlo	16-20 Years	3-5	All	Rural	3	2	2	3	3	4	2
Bridget Hiddad	6-10 Years	3-5	All	Rural	5	4	5	4	3	4	3
Eva Ashton	4-5 Years	9-12	S	Suburban	3	3	3	2	3	3	3
Frank Jackson	25+ Years	6-8	S	Suburban	3	3	2	3	2	2	3
Franny Daniels	25+ Years	6-8	S, M	Urban	3	4	2	4	3	2	3
Haddie Calhoun	11-15 Years	6-8	S	Suburban	4	3	2	3	3	4	4
Harry Jones	25+ Years	9-12	S	Suburban	3	2	3	3	4	2	3
Jackie Tackler	11-15 Years	6-8	S, M	Suburban	4	4	4	4	3	4	3
Lindsey Crandall	4-5 Years	6-8	S	Urban	3	2	3	3	2	3	3
Lori Jeppson	16-20 Years	3-5	All	Rural	3	3	4	3	3	3	4
Louie Cross	16-20 Years	9-12	M, E	Suburban	3	3	3	3	3	3	3
Mandy Morwall	21-25 Years	K-2	All	Rural	3	2	2	3	3	3	3
Mikayla Lentil	4-5 Years	6-8	S	Urban	3	3	2	3	**3**	2	3
Mike Sanders	16-20 Years	9-12	S	Suburban	5	2	2	1	3	1	2
Pam Kronkite	6-10 Years	3-5	All	Rural	4	3	4	4	3	3	3
Paula Ringo	25+ Years	9-12	S	Rural	4	3	3	3	3	3	2
Phil Ericson	16-20 Years	9-12	S	Suburban	3	3	4	3	3	3	3
Stacy Ardlow	21-25 Years	3-5	All	Rural	3	3	3	3	3	3	3
Stuie Lucia	4-5 Years	9-12	S	Urban	3	3	4	3	3	2	1
Wendy Michaels	11-15 Years	6-8	S	Suburban	4	4	5	**5**	5	4	4
Zeynup Neill	16-20 Years	K-2	All	Rural	3	3	2	3	2	4	2
				Averages	3.43	2.95	3.05	3.14	3.00	2.95	2.86
				Std. Dev.	0.68	0.67	1.02	0.79	0.63	0.86	0.73

**Scores correlate to Informed* (5)," "*General* (4)," "*Emergent* (3)", "*Problematic* (2)," or "*Absent* (1) categories

When analyzed by grade band taught, grade bands had no significant differences (i.e., K-5, 6-8, 9-12). Instead, findings showed apparent differences between individuals within grade bands. To clarify, some teachers had higher scores across all categories while others did not. The standard deviations within categories ranged from 0.61 to 0.98, and scores ranged from "Informed (5)" to "Absent (1)." The categories with the highest averages were understanding engineering knowledge as *contextually responsive* and *personal/individual*. The lowest averages were seen in *social*, *empirical*, and *interdisciplinary* categories.

The categories for which the most significant amount of "General (4)" or "Informed (5)" scores were assigned were recognizing engineering as *solutions-focused* and *social*. The categories with the least amount of "Informed (5)" or "General (4)" scores were engineering as *solutions-focused* and *interdisciplinary*. As such, there was the most variation within understandings of engineering as *solutions-focused*. This variation is illustrated qualitatively in further detail below (see VNOEK Responses).

Interestingly, there were apparent differences between those who had taught STEM courses between 4-15 years and those who taught longer than 16 years. Across STEM teachers with 4-15 years of experience (43%), there were only three categories for which participants had "Problematic (2)" averages. These were understanding engineering as *personal*, *societal and cultural*, and *interdisciplinary*. However, those with more than 16 years of STEM teaching experience displayed "Problematic (2)" averages across several categories. These included all categories except for engineering as *contextually responsive* (where averages were emergent).

All teachers identified themselves as 'STEM teachers' on the pre-survey and also identified their subject(s) taught. There were slight differences when comparing results with teachers' subject area(s) taught. However, *math* and *engineering* teachers showed the greatest understandings of engineering and had more uniform VNOEK scores across categories. Responses were not significantly different between those teaching just *science* (e.g., life science, earth science) and those elementary teachers who address *all subjects* in their classrooms. To note, however, only three math or engineering teachers volunteered to participate in the current iteration of this project.

Analyzing data by teachers' location showed the most considerable differences in average VNOEK scores. Teachers who identified working in suburban schools scored highest across all categories, followed by those in rural and urban settings. The only categories in which all three locational groups scored similarly were understanding engineering as *contextually responsive* and *personal/individual*.

VNOEK Responses

As shown above, teachers' VNOEK responses varied across and within individuals and categories. Here, categorical examples are provided. Those with "Absent" views did not respond to the category (e.g., no available excerpts). To remind the reader, the VNOEK questionnaire focuses on a water filtration and bridge-building scenario in which engineers must design, model, and test a new filtration system and concrete-type bridge-anchoring material. To do so, they must consider the community's needs and specific criteria and constraints. Participants' responses were therefore centered on clarifying the aspects of these scenarios and how they relate to engineering, and they were not asked explicitly about NOEK tenets.

Contextually Responsive. Describing engineering as *contextually responsive* meant accounting for criteria, constraints, and changes to the process over time. Zeynup, whose responses were emergent, described in one example how "The budget for the project will be different for each community. And even minor points, like aesthetics, would be different in different communities. And more and more differences in between." Zeynup accounts for some criteria, constraints, and differences but not others. Conversely, Bridget's responses here were considered informed. She posed several questions about criteria and constraints, asking:

> *How many people use the water? What times of day is the usage most prevalent? What are the current materials being used? Are any of those materials functioning well? What will people use this for? Will you need a specially trained workforce to manage and operate a new system? What materials are available to use in your area? How long do you want the filtration system to last? (Bridget, Informed)*

Empirical. Understanding engineering as *empirical* means acknowledging that it is evidence-based and relies on modeling and optimization. Some, such as Mikayla, problematically misunderstood an engineering model to be a model of engineering design. She wrote that a model was "Planning, designing, collecting, analyzing and implementing (testing)." In another problematic response, Paula talked about students rather than engineers. She wrote how, "Students will need to design the system, make a prototype, and test it. Data analysis will also take place." Aside from mentioning "students," while Paula emphasizes evidence and modeling, she does not mention optimization. Conversely, Louie describes emergently that an engineering model "…simulates a solution to a problem. Creating the model will make problem solvers think about the problems to be solved to create the final solution. What are the overall goal, budget restraints, and physics/engineering problems that must be overcome?" This is a more informed conception, but the idea of optimization is markedly absent.

Solutions-Oriented. Thinking of engineering as *solutions-oriented* encompassed recognizing that engineering solutions can be new artifacts, systems, or processes. Lori wrote problematically, "I think this is engineering because this system must be designed, built with a knowledge of the engineering process. This must be a methodical process." While she emphasizes a new system in her responses (as shown here), she does not discuss artifacts and refers to the design as “methodical” rather than dynamic and iterative. When referring to what engineers must accomplish in the water filtration scenario, Pam described generally how “There may have been changes to the land. Something [a system] needs to be designed in order to get the new material there. Because the material is new, it needs a new machine to transport it [artifact].” In this case, Pam describes a new system and artifact but does not suggest the design process may change (across any of her other responses).

Personal/Individual. Understanding engineering knowledge as personal/individual meant addressing how engineers can generate unique solutions to problems based on their personal, professional, and academic experiences. Brenda wrote emergently about it, “Any time people work together, ideas are created. They then can build from each other's knowledge and create something even stronger, better than one designing it by themselves.” While she addresses the personal nature of engineering knowledge, she does not specify how engineers are involved (beyond “people” more broadly). In a more informed fashion, Wendy describes how “the genius of diverse teams” is that “Each engineer will bring their own experiences and background knowledge to this project. They each could bring a different idea for a design, which they can possibly incorporate together. The design will be stronger if each engineer has different ideas that they can incorporate and test.”

Societal and Cultural. This category refers to engineering knowledge as affected by and effective of aesthetics, problems, and expectations of communities. When asked if and how the community will affect and be affected by the bridge design, Franny described problematically how “Yes-the people who will use the bridge should have some input because of traffic/location. As for the concrete material - only if it affects the nature of the ecosystem [will it affect the community]. Franny addresses the community’s expectations but does not address how the bridge will affect the community. In a more informed way, Wendy emphasizes both the bridge’s effect on the community and the community’s impact on the bridge:

> “*What's the level of traffic? How much does the community care about aesthetics? How stable is the substrate at the bottom of the lake? How much boat/ship traffic will travel under the bridge? If the communities on either side of the lake have never been connected before, the increasing contact with the other communities creates a more shared culture. More concern about the larger regional community, not just their own individual community. (Wendy, Informed)*

Social. Engineering knowledge is social because it is often team-based and develops through clients’, peers’, and colleagues’ input. Emergently, Eva describes how “They [engineers] will not have identical ideas for the project. Just like with any group work, everyone contributes different viewpoints and solutions. They all may also have different skill sets.” While she responds to the social aspects of engineering, she does not talk about the importance of clients’, peers’, and colleagues’ input. In a more general example, Jackie describes “the group” of engineers who each “bring a different perspective to solve a problem,” also saying that “The engineers need to take into account the community voice and if they feel the design meets the needs of the community." Here, additional aspects are addressed, but the role of peers' and colleagues' input is still unclear.

Interdisciplinary. Lastly, engineering knowledge is interdisciplinary as science, technology, and engineering co-develop. When asked how science and technology related to engineering, Mandy described emergently how "Everything is based on science and technology in some way. There is always a new need for technology, and it is usually based on previous science. Biomimicry, for one." Here, she talks about how science and technology underpin new technologies but is a bit unclear about the role of engineering. Similarly, Bridget wrote emergently how "You need both [science and technology] in order to engineer anything. Computers are used to create the mathematical angles needed to support the weight of the structure." In a more general sense, Lori describes how:

> *Science and technology relate to engineering because one must consider all of these to come up with the best design. To design a good bridge, one must consider the science of concrete curing, the bridge's structure, the metals to use, and any new techniques that may be available through computer analysis. (Bridget, Informed)*

Here, Bridget goes a bit more in-depth. She does not quite describe engineering, technology, and science as co-developing but instead as used to support each other on an as-needed basis.

Discussion

Findings suggest the need for additional exploration and comparison of teachers' VNOEK across contexts (e.g., grade levels, experience, subject area) using this survey instrument. When taken together, teachers' VNOEK understandings could be considered emergent, but there were apparent differences between individuals' responses; by years and subject areas taught and location. So connected, the VNOEK instrument was robust enough to capture granular differences between participants' responses.

Epistemologically, teachers appeared to best understand engineering as contextually responsive and as a human (personal/individual) endeavor (Bucciarelli, 2001; Hasanah, 2020; Johri & Olds, 2010). Responses were scored highest in these categories and did not differ widely by grade band or subject area taught. This trend could reflect the portrayal of STEM teaching across the literature as a hands-on, real-world, and collaborative form of instruction (Lachapelle & Cunningham, 2014; Pleasants, 2020; Roehrig et al., 2021) as well as national standards that emphasize 21st-century skills such as collaboration, adaptability, and cooperation (Ford, 2015; NSTA, 2020). Teachers least understood that STEM disciplines codevelop and are codependent; the nature of engineering as a distinct discipline with discrete ideas, practices, and processes (e.g., Karatas et al., 2009; Lawson & Dorst, 2013; Lewis, 2006). We suggest the overall trend of emergent views was congruent with literature that suggests teachers are generally unfamiliar with engineering, technology, and engineering design (Antink-Meyer & Meyer, 2016; Hsu et al., 2011; Karatas et al., 2011; Knight & Cunningham, 2004). However, some did appear to have more informed views. More research is needed to understand how these views were informed by teachers' own engineering-related experiences and the implementation of engineering in their classrooms (Capobianco et al., 2018).

When viewed through the lens of participants' experience with STEM teaching, results appeared to suggest that teachers who have taught for longer than 15 years held less-informed views than those with less experience. Considering teachers' wisdom of experience (Shulman & Wilson, 2004), this trend was somewhat surprising. However, we posit this trend may reflect the ever-growing attention to pre-college, engineering design-based STEM teaching since the early 2000s (European Commission [EC], 2004; PCAST, 2010; NGSS Lead States, 2013; NRC, 2010; National Academy of Sciences [NAS] & National Academy of Engineering [NAE], 2014), yet more recent availability of engineering design-related professional development (Bryan & Guzey, 2020). That is to say, some less-experienced participants could have had more engineering experiences during their schooling and, therefore, may be more familiar with engineering. In addition, VNOEK scores for more experienced teachers (e.g., 15+ years) may reflect a recognition of their students' engagement in engineering as it intersects with their teaching practices (e.g., the tension between authentic and accessible K-12 engineering). Put simply, teachers' views may have shifted over time in response to their classroom enactment and their students' engagement. Aligned with this point, some participants used the term "students" alongside "engineers" in their VNOEK responses.

Organizing results by teachers' subject areas, trends showed those math and engineering teachers held slightly more informed VNOEK views than others. This was perhaps not a surprising trend (e.g., those related to engineering had more informed views). Worth noting, however, is that despite the small sample size (n = 21 teachers) in this study, the VNOEK instrument was able to capture slight differences in teachers' responses that were supported by independent researcher analyses. Interestingly, teachers' VNOEK was different when considering where they taught (e.g., urban, suburban, rural). We suggest that this could be related to their (lack of) personal contact with engineers or familiarity with the water filtration and bridge-building scenario presented in the VNOEK. In other words, participants in suburban areas may come into contact with engineers, water treatment facilities, and bridges more than those in urban or rural districts. That is to say, teachers' VNOEK may differ across different geographies.

Limitations

There were inherent limitations to this study. In the foreground, this population was a limited group of experienced STEM teachers. Given the voluntary nature of participation, while we did have equal representation of individuals teaching different grade bands (i.e., elementary, middle, high school), we did not have the same concerning different teaching disciplines (i.e., S, T, E, and M). However, all these participants identified themselves as STEM teachers and utilized interdisciplinary STEM instruction in their classrooms. We were also limited by the instrument. While previously validated in similar populations, the instrument is focused on a very contextualized engineering problem with which some may need to be more familiar. However, it did serve to parse out granular differences between participants' responses.

Implications and Conclusion

Findings provide concrete directions for further VNOEK research for engineering teachers and education researchers. First, the VNOEK proved a practical and robust method of identifying teachers' views of engineering knowledge. It was not only able to capture larger trends but also clearly differentiate between responses within categories. Using this validated instrument, more work is needed to understand teachers' VNOEK across school contexts (e.g., location, grade level, experience, and discipline). Teachers' views may also change over time as they repeatedly implement engineering design tasks. As teachers make sense of learning to integrate engineering into their classrooms, they need access to targeted resources that consider their VNOEK and offer a bridge to more informed understandings.

Teachers' views in the current study offered potential entry points to support deeper epistemic understandings. At the individual and aggregate levels, the VNOEK revealed areas where teachers were more informed and areas where more attention is needed going forward. On its face, the VNOEK offers a method for teachers and teacher educators to reflect on their epistemic views of engineering.

Connected, more attention is needed to understand how the VNOEK prompt itself may be used to support teachers' views, as well as where the instrument may be expanded (e.g., different scenarios, more or less explicit engineering emphases) to be more equitable to teachers' wide range of views of engineering knowledge. This is to position the VNOEK as a formative means of self-assessment, as it is underpinned by the research-based nature of engineering knowledge. As engineering becomes more ubiquitous across pre-college national STEM reform, it is more important than ever to support teachers' sensemaking by enacting authentic yet accessible engineering in their classrooms. Teachers draw upon their related pedagogical and disciplinary knowledge when creating and adapting engineering design-based curricula to fit their students' needs. If teachers do not hold informed views of engineering, they may be unable to meet these reform- and curriculum-based goals. However, engineering needs to be recognized in the STEM classroom for what it is: an iterative, collaborative, and dynamic process for providing solutions to our global problems and desires. The VNOEK instrument appears to offer a means for identifying and supporting this awareness.

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