Instructor Beliefs and Practices at the Periphery of STEM

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As a practice, modeling is beneficial for students. For students to have the opportunity to do modeling, instructors must choose to incorporate it into their courses, a decision based on the instructors' beliefs about modeling in and out of the classroom. To expand applicability and generalizability of results and theories, to expand the focus of mathematics education research to domains trending mathematically, and to work towards incorporating modeling into other classrooms, we interviewed 10 STEM instructors in domains atypical to the current literature base. Analysis indicated this demographic of STEM instructors held beliefs about modeling in and out of the classroom similar and different to those documented about typical STEM instructors. However, similar beliefs are more nuanced than previously reported.

Keywords: Teacher Beliefs, Modeling, Integrated STEM.

Mathematical modeling (hereafter: modeling) is beneficial for students for multiple reasons: from developing general competence towards creative problem solving to helping acquire, learn, and keep mathematical concepts by providing motivation for and relevance of mathematical studies (Blum & Niss, 1991). However, facilitating modeling tasks is challenging, and many STEM instructors cannot easily find time in their courses to dedicate to modeling. Because of this, one obstacle in incorporating modeling tasks into STEM students' coursework is persuading STEM instructors that doing so is achievable and worthwhile.

In general, instructors' judgements about their pedagogical practices arise from their beliefs (Pajares, 1993), a link that has been documented by many researchers in many contexts.: k-12 science (Haney, Lumpe, Czerniak, & Egan, 2002), K-12 mathematics (Bray, 2011; Clark et al., 2014; Jacobson, 2017; Yurekli, Stein, Correnti, & Kisa, 2020), college sciences (Gibbons et al., 2018; Pelch & McConnell, 2016), and engineering (Borrego et al., 2013). The first step in addressing STEM instructor's beliefs about a topic, such as modeling, is to first document their differing beliefs about the construct (Nathan et al, 2010). Thus, a better understanding of modeling's place might be in the curriculum, can inform efforts to persuade STEM instructors that teaching with modeling is an achievable objective.

Across STEM fields, research has documented instructors' beliefs about modeling (as a professional and educational activity), the integration of mathematics into their courses, and the characteristics of successful STEM students where STEM was typically taken to mean physical sciences, engineering, and computer science. However, other fields, such as psychology, biology, and economics, are becoming more mathematical. For fields whose roots are not mathematical, or even statistical, there is still much to be learned about the how these professionals conceptualize modeling, and how they view the role of modeling in their course work. Articulating an inclusive, and empirically informed, account of what constitutes modeling can provide novel perspectives about modeling instruction absent from the literature. Such perspectives can better inform the teaching and learning of modeling by expanding the contexts in which modeling is studied and potentially include a demographics of students not currently accounted for in literature. That is to say, their perspectives are important to include because they are STEM professionals who teach STEM students. Indeed, even the NSF classifies anthropology, psychology, and economics as STEM fields (NCSES, 2014).

This study lays the groundwork for describing an inclusive view of STEM instructors' beliefs about modeling. The goal of this paper is to extend what is known about STEM instructor's beliefs about modeling in STEM majors course work by providing the perspective of STEM instructors not currently accounted for in the current literature base.

Literature Review

Some studies exposed the contrasting views held by STEM instructors with regards to their field's relationship to mathematics which insinuate a instructor's conceptions about modeling's place in their courses. Holmberg and Bernhard (2017) interviewed 22 university instructors who taught content related to Laplace transforms. Some instructors believed that mathematics, physics, and technology are inseparable; others verbalized the opposite view, that these fields are not related at all. Nathan et al. (2010) developed a measure of STEM instructor's beliefs about engineering students' success. They studied differences in beliefs and practices between STEM high school instructors with masters' degrees and instructors using an integrated curriculum. Instructors with master's degrees were least likely to identify sources for engineering support, least likely to claim their class was integrated with STEM, and more likely to agree that students needed to be high achieving to be successful in a STEM career. Bergsten, Engelbrecht, and Kågesten (2015) interviewed two professional engineers about their views of conceptual and procedural mathematics skills in engineering education and practice. One engineer, Robert, from Sweden worked in technical physics and electrical engineering. The other engineer, Ben, was a civil engineer from South Africa. Both engineers held that conceptual mathematics skills are the most important for engineering education. However, Robert emphasized the connection between conceptual and procedural actions, while Ben stated that procedural mathematics skills are not necessary. Bergsten et al. (2015) conjectured that this difference was due to the engineers' differing fields and backgrounds. These studies empirically showcase two ideas about modeling and curriculum present in Kaiser (2017), the idea that different fields view applied mathematics and pure mathematics as either separate and should be taught separately or inseparable from the subject and was an inherent part of other sciences and should not be taught separately.

Other literature focuses on STEM instructors' beliefs about characteristics of successful STEM students, particularly their beliefs about their students as learners of science, mathematics, and, the intersection, modeling. Faulkner and Herman (2016) interviewed engineering and computer science instructors about the skills students needed to be considered mathematically mature. Results indicated that the instructors valued algebraic fluency, quick computations, symbol sense, ability to use online tools to solve mathematics problems, confidence, and other modeling skills are necessary for a student to be called mathematically mature. Similarly, Gandhi-Lee et al., (2015) interviewed biology, chemistry, computer science, engineering, geoscience, health science, mathematics, and physics instructors. Their participants held that to be successful, students must be curious, independent problem solvers, with positive attitudes. Additionally, these instructors identified mathematics overall as a roadblock to success, and specifically identified algebra as the minimum requirement for success.

The field has also documented how professional engineers, and instructors of engineering and mathematics view modeling as a construct (see Drakes, 2012; Frejd & Bergsten, 2018; Gainsburg, 2013). Instructors in these fields, as well as secondary and post-secondary science teachers, have not reached consensus when describing the role of mathematics in their classes. STEM instructors more broadly, including computer science, health and geo sciences, biology, and chemistry have well-considered characterizations for student qualities they believed contributed to success. The field has yet to learn how disciplines at the periphery of the definition of STEM, such as geography, psychology, anthropology, and economics, conceptualize modeling and how those STEM instructors view the role modeling plays in the education of their STEM students. It is thus unknown whether these results generalize to the broader population. Attending to the beliefs and perceptions of the peripheral STEM disciplines will strengthen applicability and generalizability of results and theories expressed in the current literature, will expand the focus of mathematics education research to incorporate domains that are trending mathematical, and will work toward meeting a societal need by getting more modeling into these other classrooms. With these goals in mind, the purpose of this study is to answer the question: what is the role of modeling in the education of undergraduate STEM majors, according to non-traditional STEM instructors and how do their accounts comport with existing research on traditional STEM instructors?

Instructors' beliefs have commonly been studied using a combination of qualitative and quantitative methods (see Bray, 2011; Gibbons et al., 2018; Haney et al., 2002; Nathan et al., 2010; Pelch & McConnell, 2016). Typically, observations are analyzed qualitatively to study instructor practices while instructors' beliefs are measured using surveys and statistical models are used to test associations between beliefs and practices (Philipp, 2007). This approach has been critiqued in the broader higher-education literature for the underlying assumption that there is a clear causal relationship among instructors' conceptions, practices, and student learning (Devlin, 2006). Thus, qualitative methods, such as thematic analysis, are preferred when studying individuals' beliefs (e.g., Bergsten et al., 2015; Drakes, 2012; Faulkner & Herman, 2016; Frejd & Bergsten, 2018; Holmberg & Bernhard, 2017). However, a balance must be struck; overly broad characterizations lose descriptive power necessary for explaining individuals' instructional choices. Consequently, studying the relationship between teacher beliefs and instructor practices necessitates a fine grain size to allow for local causal models that are consistent within participants and their circumstances (Speer, 2008).

Theoretical-Methodological Lens

We adopt the stance that a person's identity, personality, desires, and importantly, their beliefs are embedded within the stories they tell, an assumption of narrative inquiry (Loong, 2019). Following Pajares (1993), we take beliefs to be knowledge a person holds that is either descriptive, evaluative, prescriptive, or any combination of the three (Pajares, 1993). Following Polkinghorn (1995), we constitute a story as a narrative preserving "the complexity of human action with its interrelationship of temporal sequence, human motivation, chance happenings, and changing interpersonal and environmental contexts." (p.4). Thus, a story is more than a description of what happened at a point in time, it has also an underlying structure connecting the events through choices made by the storyteller. The structure, or plot, aids in identifying how individuals connect the events in their lives as precursors for and consequences of the choices they make. This orientation affords a view of STEM instructors' stories as embedding their beliefs about the role of modeling in the education of STEM majors, as follows:

A STEM instructor has beliefs about modeling (even if they do not use the label "modeling"), which include beliefs about modeling in all contexts including their research, their industry jobs (if applicable), and their teaching. An instructor can have an experience, a notable instance salient to them, that may affect their beliefs about modeling. Consequently, analyzing the stories STEM instructors tell about their experiences with modeling in their personal-professional lives and their teaching will afford inferences as to the nature of those beliefs. Descriptive-analytic accounts of the instructors' stories also articulate explanatory mechanisms for how individuals came to hold their beliefs, data useful waypoint for future research.

Methods

We conducted this study at a large southwestern university in the USA. We selected instructors from fields that the NSF (NCSES, 2014) has identified as STEM fields yet are not typically represented in modeling or mathematics education literature: economics, anthropology, geography, and psychology. After identifying majors associated with these fields, we recruited instructors who had recently taught courses for those majors. The population has two advantages for addressing the research questions. First, STEM instructors who are professionals are more likely to have experience with modeling in their undergraduate studies, graduate studies, research work, or industry job. Second, insisting the STEM instructor primarily teaches STEM majors increases the likelihood that the instructor has considered the role of modeling in the education of majors in their classes. In total, the 10 participants of this study were: two economists, two anthropologists, three geographers, and three psychologists.

Data were collected through episodic narrative interviews (Mueller, 2019) conducted over zoom. The episodic narrative interview is a fusion of three other qualitative methods: semi-structured interviews, narrative interviews, and episodic interviews. This approach enabled cross-participant comparisons, provided a strategy for looking at experience-focused narratives which allowed for the participants' views of salience to be prioritized, and allowed for exploration of the target phenomenon (Mueller, 2019). In this way, experience-centered narratives of research and teaching were prioritized while also targeting the scope of each interview toward instructors' beliefs about modeling, generally, and in the classroom through their own salient experiences. Then the salient-to-participants aspects could be inferred and compared across cases and to the extant literature.

In episodic interviews, the interviewer typically starts the interview by asking a question that defines the phenomenon of interest, and then follows with a question to elicit an episode from the interviewee's everyday life in where the phenomenon of interest would take place. The interviewer then asks questions about the phenomenon of interest within that evoked situation (e.g., Romaioli & Contarello, 2019). Similarly, episodic narrative interviews are constructed to funnel the interviewee's story towards the phenomenon of interest (Mueller, 2019). We organized the interview around two sub-stories, building one cohesive story to state and explains the instructors' beliefs about modeling in their classrooms. The first sub-story focused on the professor experiences with modeling outside of teaching. The second sub-story focused on the instructors' experiences with modeling while teaching.

We used analytic techniques informed by narrative inquiry (rather than the more common coding techniques that are appropriate when a pertinent, codified framework exists, which our review of the literature did not reveal). We began with thematic analysis to identify major themes, understood to be patterns within the data (Braun & Clarke, 2006) salient to the participants. We then used emplotment analysis (Polkinghorn, 1995) to probe and then reconstruct the data. Questions such as how does modeling fit into your class as a whole? and How does modeling fit into your students' major (course)work? elicited responses that intimated the instructors' beliefs about the role modeling in the education of STEM majors.

The data were analyzed at the latent level (Braun & Clarke, 2006) with the grain size of analysis being finished thoughts. A finished thought was one or multiple statements about the same topic. A new thought was started when there is a turn in topic of the interview. As informed by Braun and Clarke (2006), the analysis was conducted in five phases: becoming familiar with the data, generating initial codes, looking for themes within the initial codes, reviewing those themes for refinement, and defining the themes. This analysis produced a list of major themes that emerged from the data when focusing on the participants conceptions of modeling in and out of the classroom and curricula. The results of this part of analysis gave a group of codes providing overarching ideas about modeling in and out of the classroom. For example, one idea about modeling was modeling is statistical, and an idea about modeling in the classroom was students are not mathematically prepared for it. To personalize a participant's particular set of beliefs, we identified each participants' core beliefs, where core beliefs are the set of beliefs held by a person that was showcased through multiple instances. This was done to get a nuanced view of the participants beliefs, as a participant could have answered an interview question with a polite response and not necessarily their truly held beliefs. This was done by using the Max Maps feature in the qualitative data software MAXQA. The feature visualized the highest-frequency codes present in a single interview. Codes were transferred to the participants' maps only when they were at least partially constitutive of a core belief.

To account for important background information, significant experiences with modeling in daily life, and significant experiences with modeling while teaching, we used ideas from emplotment from narrative analysis to construct individual narratives about each professor. The first step in emplotment is to identify the end goal. In this analysis, the end goal was each participants' set of core beliefs. The next step is to hypothesize a plot which is then tested against the data. This is done by asking questions like: do any of the major events conflict with this current plot structure? If a major event from the data does conflict, then changes are made to the plot to accommodate and the new revised plot is tested against the data again. While testing the plot against the data, one must ask if each event is pertinent. If an event is not pertinent to the plot, that data is culled from the story in a process called narrative smoothing (Kaasila, 2007; Polkinghorn, 1995). This process is undertaken until a cogent plot emerges that considers all of the pertinent events, this forms the plot outline. This plot outline is then filled in with data elements to form the final coherent story (Kaasila, 2007; Polkinghorn, 1995).

This analysis produced individualized narratives for each participant that tie their core beliefs with important background, and significant experiences with modeling both in daily life and while teaching. It is important to note that the beliefs about modeling in and out of the classroom highlighted by this analysis are not the only ideas about modeling held by the participants in this study. For the purpose of this paper, we present the most salient beliefs about modeling in and out of the classroom at the time of the interview. This helps with identifying beliefs that are most important to the participants but does not identify all the beliefs the instructor might hold. After the construction of these individual narratives, we reanalyzed the narratives, again using techniques from thematic analysis (Braun & Clarke, 2006), to look for overlap between the themes we identified and those present in the literature. This analysis allowed us to make broad-stroke comparisons of our participants' beliefs and the existing literature.

Results

The literature suggests there are differing ideas about the role of mathematics, and thus of modeling, in science, technology, and engineering (STE) courses. The two big ideas about the role of mathematics in STE is that of inseparability (STE cannot be taught without also teaching mathematics) and isolation (STE and mathematics are taught in their own courses). Both sentiments were also found among the core beliefs of our participants. Karter, an economist, and River, a geologist, were insistent that mathematics was inseparable from their courses' content. For example, Karter said

> Karter: I tell them [his students] economics and mathematics are inseparable. So, there is no way. If you come to this class and you think that I'm just going to chit chat and not write

an equation or any numbers on the board, and then you better drop out of this classroom. I let them know, they know what is coming ahead of them. But, then I motivate them.

In contrast, Phoenix, an anthropologist, talked about mathematics as a tool to be taught in another class.

Phoenix: Well, I'm very glad to have them [economics majors] in my class, but it's really for the economics program to teach them that part of it [the mathematics behind some theories]. Like I said, anthropology is a high-level discipline meaning it's at a high level of abstraction. If they want to do economics, they really do need to learn, they need economic analysis classes. But that's not my job. That's not my job and truthfully, I'm not really qualified to do it.

We do not claim that differing conceptions of STEM integration originate in the participants' fields. The contrasts seem to be rooted in the instructors' salient experiences with mathematics and modeling in their professional lives and teaching. For example, Karter told a compelling story of studying mathematics in his youth and explicated many examples of using modeling in his career. In contrast, Phoenix did not share any salient experiences with modeling in his research or while teaching.

Gandhi-Lee et al. (2015) and Faulkner and Herman (2016) showcased how STEM instructors believed that mathematics proficiency was important for students in STEM fields. More specifically, Gandhi-Lee et al. (2015)'s participants talked about mathematics as a roadblock, and how algebra was the minimum for mathematical preparedness. Almost all participants (9 of 10) in our study explicitly voiced a similar sentiment, that mathematical preparedness of students was a roadblock to implementing modeling tasks in the classroom. One anthropologist, called Phoenix, did not hold this core belief, did not communicate salient examples of using modeling or any mathematics in the classroom. While almost all voiced level of mathematical preparedness as a roadblock to including modeling in their courses, we observed a level of idiosyncrasy in how each participant operationalized preparedness. Predictably, some instructors operationalized mathematical preparedness to mean algebraic fluency or a certain level of proficiency in calculus. For example, Quinn, a psychologist, explained that he had to scale back the difficulty of the mathematical analysis in an in-class experiment.

Quinn: I, over the years, I still do that in the class but I've kind of scaled back the complexity and difficulty of the exercises. I've found that I just needed to and the main reason… Where a math problem that I thought should be pretty simple if you've just taken college level, I don't know, algebra for example. It wasn't anything too crazy that I gave the students. Even then some students had difficulty with it. Not all, some students did just great but I felt that I needed to kind of scale back the complexity of those problems over time but still using them.

Haven, a psychologist, suggested that mathematical preparedness meant fluency with graphical representations and their meanings. She recounted a conversation with one of her graduate students working on a research problem. The student was having difficulty labeling the scatter plot that would illustrate their hypothesis for statistical testing. While recalling this conversation, Haven lamented that students, more generally, were not skilled with graphical representations. She explained that graphical expressions were most important for her students because specifics about what statistical models to run could be looked up later.

Haven: If you can't figure out what's the label on our scatter plot, if you can't figure out what the Y and X axis should be labeled, take a step back and think through what you're doing. I guess that's not an issue of what buttons to click or what the test is called. I was like, "I can tell you what the test is called." Once you get that to me, that's the work I want to see you doing is thinking through graphically how to depict the data. Once you do that work, then you also know what to Google.

Both psychologists teach STEM majors in a psychology department. However, their operationalization of mathematical preparedness was quite different. This is partially due to the courses they teach. Quinn's classes tend to lend themselves more to mathematical exploration than Haven's. This might also be partially due to their differing backgrounds. Both have experience studying mathematics as students themselves, but the types of mathematics are vastly different. Haven spoke mostly of studying mathematics in her statistics and methods courses, while Quinn studied mathematics and physics at both the undergraduate and graduate level. Overall, there was broad consensus that mathematics was a roadblock for students, and that this roadblock was common in their fields. However, when delving deeper, there was no clear pattern of what was meant by mathematical preparedness based on discipline.

Discussion

Our study builds on and extends a synthesis of literature describing beliefs held by STEM instructors about modeling in the classroom through documenting perspectives of instructors from STEM fields not typically included in the literature. This work was necessary as more fields on the periphery of STEM come to rely more heavily on mathematics and statistics.

Overall, there were sentiments held in common about modeling in and out of the classroom shared among these non-traditional STEM instructors and traditional STEM instructors, such as mathematics knowledge being a barrier to implementing modeling in the classroom. However, what is meant as mathematical preparedness seems to be idiosyncratic to the individual professor and partially dependent upon the specific course content. This implies that discipline-level analysis may not be an appropriate grain size for investigating the mathematical barriers students face. We do not claim that there are no differences according to discipline, but we observed differences within disciplines indicating that using discipline to differentiate participants may be too broad. Future research endeavors to uncover instructors' beliefs and practices about modeling in STEM may wish to be cautious when constituting discipline as an independent variable because idiosyncrasies of the instructor's beliefs imply idiosyncrasy of instructional decisions. Additionally, beliefs about mathematics' role in instruction was also as mixed as it was in Traditional-Stem focused literature (Holmberg & Bernhard, 2017; Kaiser, 2017; Nathan et al., 2010). Because instructor's beliefs influence their pedagogical decisions, this differing view of mathematics' role in instruction must be accounted for in future work on persuading STEM instructors modeling is a doable and worthwhile endeavor, but we do not recommend accounting for it at a discipline-based level.

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