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How Math Education and Engineering Education Talk About Mathematics Responsiveness and Equity: A Narrative Literature Review

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Comparing Math Education and Engineering Education Approaches to Responsiveness and Equity through a Narrative Literature Review

Introduction

This conceptual paper explores the potential and constraints for creating responsive and accessible mathematics curriculum within engineering educational pathways. Within engineering education, mathematics is positioned in a number of key ways: as a prerequisite to engineering (e.g., Calculus), as a skills gap that forms an identity (i.e., calculus-readiness), and as a shared abstract language for representing engineering concepts (e.g., using mathematical symbolic language in a statics class). For engineering education research and practice, the mathematics realm is typically secondary, not primary. Within mathematics education, however, mathematics is the primary investigation. There is a potential for better understanding the mathematical aspects of engineering through conversation with the math education community.

Mathematics can also become a major equity barrier for engineering students whose high school preparation did not offer advanced mathematics courses. About 50% of high schools nationally offer AP Calculus, while only 38% of schools with majority Black, Latinx, and/or low income offer AP Calculus (U.S.Department of Education, Office for Civil Rights, 2018). At the university where we are now located, with a large Hispanic population from low-income and rural communities, over 90% of students are not able to place into Calculus in the first semester with many placing in Algebra or college math. The extremely long math journeys become a barrier for these students becoming engineers. Further, while the local university has a lot of insight and direction for creating more responsive curriculum for engineering students, the relatively abstract topics of college mathematics sequence may not lend themselves as well to crafting education that supports students funds of knowledge or creates responsiveness and inclusivity.

This conceptual paper will interrogate the ways mathematics education research and engineering education research treats mathematics, to look for insight into issues of creating more equitable and responsive mathematics education for engineers. My overarching questions to focus the study are:

- What are the differences between mathematics education literature and engineering education literature?
- How can those differences be leveraged to inform engineering mathematics / math within the engineering education pathway?
- What ideas from math education research can be borrowed from and inspired to help inform engineering education regarding mathematics?

Additional specific questions of interest include:

- What are the ways mathematics and math learners are positioned in engineering education and mathematics education respectively? (For example, positioning as a gateway prerequisite, as central curricular focus, as equity challenge).
- How do mathematics educators and engineering educators seek to create responsive and equitable curricula? (For example, how do the two disciplines assess and support their students’ funds of knowledge?)

The paper will utilize a narrative literature review to characterize the differences that emerge through the investigation of the two disciplines. A focused review will look for key terms (equity, responsiveness, funds of knowledge) and broader characterizations within prominent journals such as Journal of Research in Mathematics Education and Journal of Engineering Education. It is hoped that the insights from the literature review help inform the broader research community and the design of more responsive and equitable education for universities which serve low math access / low-income students.

Paper Process

This paper incorporates a scoping literature review in order to compare two disciplinary domains: math education and engineering education. We selected a scoping review to map out the differences between the two disciplines. In contrast to a more common systematic literature review which focuses on precise search terms and consistent analysis across the paper corpus, a scoping review allows a more dynamic search process and a more interpretive analysis process that allows a research to adapt the approach as they learn more about the literature. This flexibility helps generate knowledge of a relatively unknown literature (or in this case, two relatively known literatures that are rarely compared to one another). Rather than a formal systematic presentation of the findings, we incorporate a narrative literature review to discern the most significant elements of the scoping review. The narrative format allows me to emphasize interpretative significance and subjective importance (particular to the interests of the context we educate within) of various findings, rather than treating each paper equally.

The second author, an undergraduate student researcher, helped assemble the dataset. We searched key publications for significant papers, using a combination of the journal websites and the University of New Mexico library website (which automatically incorporates databses in the search). The exact search parameters adapted as the search progressed but encompassed the following:

Literature base	Venues searched	Search terms / topics
Math Education literature	● Journal of Research in Mathematics Education ● Problems, Resources, and Issues in Mathematics Undergraduate Studies ● The College Mathematics Journal ● Investigations in Mathematics Learning	● Engineering ● Undergraduate education ● Cultural responsive education ● Building on students' funds of knowledge ● Equitable education ● Pedagogical strategies (especially in undergraduate education)
Engineering Education	● ASEE conferences (peer.asee.org) ● Journal of Engineering Education ● IEEE publications (Frontiers in Education)	● Math / mathematics (must include) + additional terms: ● Undergraduate education ● Culturally responsive education ● Building on students' funds of knowledge ● Equitable education ● Pedagogical strategies

		● Math within engineering content and math as a standalone subject

We utilized a University of New Mexico library search that automatically indexes journals and databases (e.g., ERIC) to uncover key papers and journals to investigate. As we assembled literature we refined our approach. For example, an initial search using library search turned up primarily IEEE publications and no ASEE publications. Thus we added the peer.asee.org website specifically to interrogate ASEE publications. Our library database searches also uncovered publications with our search terms in STEM education and science education and these sometimes created discrepancies for classification as math education or engineering education. We did not include these publications in our paper corpus.

In analyzing the dataset, we read select papers together and discussed. We used journal titles to create the classification above and to group papers as either engineering education or math education. We looked for emergent categories and patterns that could characterize some patterns in the differences between the two disciplines. We then grouped papers into categories that represented these themes, recognizing that there was some overlap in the categories. We used specific example papers to help characterize the broader patterns we saw in the dataset.

Findings:

We organize the findings around broad topics covered in engineering education and math education literature.

Engineering Education Characterizations of Math

We begin with engineering education so that the indicative contrasts with math education literature can help inform new potential directions for engineering education literature.

Math as predictor / gateway

A common way math is positioned in engineering education literature is as a predictor of success in engineering. That prediction can stem from either a mathematical aptitude, mindset, or from a gateway course performance. A study by Kaya et al [1] examines the effects of language learning and math mindset on academic success in an engineering program. Math mindset in this study refers to having a growth or fixed mindset related to learning math; language learning mindset is the mindset for learning language, which was particularly relevant for English proficiency for their Turkish participants / context. While this paper is classified as a prediction paper, the overall topic of specific math mindset is potentially worthy of expansion in engineering education literature. Other papers on growth mindset have broad reach in engineering education (cite), but these papers have not tended to specify math mindset as opposed to a general growth mindset, engineering learning mindset, or self-efficacy.

A study by Bego et al [2] discusses the barriers in math pathways, showing how completion of early math courses predicts future graduation. In a longitudinal study of student pathways, the speed and success with which students completed their initial required four course math sequence predicted successful graduation later.

A study by Tran and Mitchell [3] in Journal of Engineering Education investigates the relationship between pre-college engineering study and later achievement in science and mathematics. Although classified as a prediction study, this reverses the more common association between math and engineering—since mathematics is usually the prerequisite to engineering and not the other way around.

Math as outcome / intervention

Math is also positioned as an outcome or targeted intervention in the engineering education literature. Kattayat et al [4] examined an intervention of "mathematics review" (a short face-to-face or online review of related math concepts) as a precursor to a physics lesson for engineering students. Another intervention called CeAMatE (which stands for Centro de Apoio á Matemática na Engenharia, or, Math Support Centre in Engineering) emphasized review of elementary math knowledge for integration into their engineering degrees [5]. Another study tested various cognitive learning strategies (e.g., retrieval practice, spacing) and their impact on math success [6]. In these studies, math skill or knowledge was the explicit outcome being evaluated, yet they are different from predictive studies (in that they seek ways to help all students achieve success, rather than predict those who achieve it).

Brandi and Garcia [7] focused on math engagement and motivation as the outcome for an engineering student population within differential equations course context. Zabala-Vargas and colleagues [8] also focused on motivation as outcome, through a Game Based Learning intervention. Motivation and engagement are important dimensions of math success that can sometimes be de-prioritized, when we think of math skills as something unidimensional or fixed. If students can increase their motivation and engagement with math, they will find the math becomes easier and their skills increase because of practice and persistence.

Another study Shadaram et al [9] used an intervention called Just In Time learning to impact performance, retention and graduation. In this study, math becomes a short intervention to ensure they understand the necessary skills preceding a specific lesson.

Finally, one study by Serrat and colleagues [17] discussed the translation of a mathematics intervention (EngiMath) from engineering education research studies to the practice of teaching and learning, noting lessons learned from the experience of that translation. This intervention couples online assessment of mathematical needs with formative feedback and student-centered online learning. This is a promising model and discussion of the translational differences, although the software does not appear widely available.

Math Education Characterizations and Contrasts

Next we overview the Math Education literature to highlight contrasts in emphasis and attention, to help highlight affordances of and insights that may be useful for engineering education.

Math Learners' Culture, Identity, and Experience

One of the key affordances of math education literature is a greater emphasis on the experience of math and the people dimensions of math learning. While we in engineering education may visit the literature on culturally responsive pedagogy as well, we rarely do so regarding the topic of math, which is a cultural domain. The math education literature highlights different models of culturally responsive math teaching

[11] [12], identity, [13] [14], approaches to equity in teaching mathematics [15] [17] [10] [19], and forms of social and cultural capital regarding math.

A significant literature on math identity [13] [14] [16] looks at the influences and impacts of math identities within math education. Perhaps moreso than other forms of identity, identification as a person who gets or can do math is a widely culturally shared phenomenon. The patterns in these identifications are heavily influenced by cultural shared narratives, such as gendered associations of math with masculinity and whiteness. Danny Martin [16] studied the identity formation of African American adults within a community college context and how they wrestled with narratives of Blackness with math. Similarly, Larnell studied the impact of racialized narratives and remediation structures on Black undergraduate experiences and their math identities [20]. He specifically highlights math learning as socially constructed, the role of math as a gatekeeper for technical degrees like engineering, and how non-credit bearing remedial courses reemphasize the lack of the system and narratives of success. As the phenomenon of being a "math person" is widespread, it may cut deeper and be more culturally salient than engineering identity, which is linked to a specific profession.

Another significant body of literature emphasizes math as cultural [11] [12]. This may also surprise engineering educators, who are only familiar with western math systems and symbols. Yet, the western base 10 system, our course sequences, our ways of teaching, and our ways of demonstrating math proficiency are only one cultural option. There are other math systems originating from other cultures, such as the indigenous Oksapmin system that uses 27 different body parts for counting within a base 27 system [36]. Nasir et al [37] also emphasized the somewhat arbitrary delineation between mathematical domain knowledge and cultural knowledge, when cultural practices can include specific basketball point systems that are useful and necessary for solving a basketball-related math problem. They problematized the domain knowledge needed for solving school math as also cultural and requiring specialized cultural knowledge, just steeped in the culture of western formal schooling.

An influential theory of funds of knowledge emphasizes the way that children's home cultural knowledge can be leveraged in creating curriculum [39]. This theory has been especially leveraged in K-12 mathematics settings [40-41]. As mathematics educators have more broadly embraced the agenda of investigating mathematical funds of knowledge, there are additional curricular materials and grey literature (e.g., blog posts) highlighting and demonstrating how to leverage mathematical funds of knowledge [42-43]. While engineering education also highlights funds of knowledge as a prominent research agenda [44-46], there is additional insight to be gained from the understanding of mathematical components of engineering as cultural and based in the home communities of learners. However, the relative emphasis of engineering education on undergraduate education over K-12 education somewhat limits the feasibility of conducting traditional community- and home-based funds of knowledge research.

Math domain specificity

While many engineering education studies tended to highlight math overall, a benefit of math education research is the attention to specific domains of math learning and practice. For example, math education studies focused on the key underlying features of Calculus that influence certain experiences [23] [30]. Math education studies sometimes focus in great depth on the specific ways a course like Algebra uses the equal sign as equivalence in contrast to Arithmetic which uses the equal sign as an operation [38]. If we consider the many specific mathematical concepts, symbols, and conventions embedded within engineering curriculum, there may be a need for a similar depth of examination to those domain-specific aspects. That is, if students encounter differences in the way a math class uses a symbol or conducts problem-solving, they may either metacognitively reach a conclusion about those two different domains or they may become confused and internalize the struggle as personal failure. Further, by drawing on the specificity of the math education literature, we could gain some more insight into those key features and help explain them to students as well.

Interdisciplinarity

A couple of specific papers discuss the need for interdisciplinarity or speak to the relationship between math and engineering. Greer [18] discusses how interdisciplinarity helps students with inclusivity, including student support, access, and sense of belonging across disciplines.

Pedagogies and Course Progressions

A large number of math education papers highlight pedagogical approaches for teaching math [20-29]. Several additional studies offer specific strategies for supporting diversity and equity within math studies [7] [15] [27] [18-19] [31-34]. One interesting study discussed gender inequity in active learning classrooms [29]—something that is also noted within engineering team projects but becomes an interesting parallel with math active learning contexts. Another insight focused on the racialized and gendered labor in students' responses to precalculus instruction [34]. These authors purport that this process reproduces inequities through participation structures in math classes for engineers. Thus, the emotional and participatory labor associated with math instruction may be an important new angle for engineering education to consider.

In addition, one prominent paper put forward the idea that rigid course sequences for math progression were not always necessary and did not support success and equity for all students [35]. As the comment about long and rigid math sequences emerges frequently in discussions of engineering degree progressions, this additional support from math education research can be helpful in discussions with math departments. It is not only engineers (who might be seen as devaluing math) who are arguing for experimenting with more flexible and accelerated math sequences.

Conclusion

In conclusion, there are several potential directions for engineering education research and practice to consider and draw on from math education research.

First, while engineering education research pays attention to human factors such as culture and identity, the underlying cultural and identity-laden aspects of math within engineering may be less explored. We can read the math education literature further to consider the experience and people aspects of math intersect the math classroom [11-13] [16] [20]. Examining this experience of math stands in contrast to treating math as an input or output, aptitude or intervention.

Second, math education may provide additional specificity in the implications and student understandings of specific math concepts and symbols which intersect engineering classes. These will help students during a course progression who must make sense of sometimes contrasting use of symbols and concepts.

Examining this specificity stands in contrast to a prominent sense in the engineering curriculum that math is one unified subject matter [21] [27] [34].

Third, math education offers many innovative or evidence-based ideas regarding teaching of math and preparing students through course sequences. We may be able to borrow these in math components of engineering. While this scoping review has helped delineate some of the key differences and affordances between the two sets of literature, additional work can be done to help distill the lessons learned across disciplines [10] [21] [24-25] [27] [33-35]. Both literatures lack much information on low-income, Hispanic-Serving, rural, and/or post-traditional student populations which are the population at our university context. We will continue to investigate and apply the insights from math education into our context while exploring our own new insights into the way to support student success in long math journeys.

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