An Engineering Education Initiative: Development of a STEM Mathematics Textbook

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***Abstract* – The debate of math pedagogy has been raging in the K-12 environment amidst chatter of revisions to science standards, namely the Next Generation Science Standards. Now instructors are caught in an awkward position to integrate the foreign subject of engineering, the "e" in STEM education, with little to no context. While teachers can enhance their knowledge of new teaching strategies through attending workshops and having university students conduct STEM academies at their school, current textbooks fail to include authentic engineering examples and thus offer little to no support to teachers. With this in mind, a math textbook which integrates engineering at a practical and understandable level would be imperative to satisfy the new standards. In addition, to effectively communicate engineering and mathematics to students, the author of the text would be an undergraduate student majoring in Engineering Education, mentored by a professor with the terminal degree in the field. The student formed a board of teachers willing to participate in the development of this text. Through preliminary research on student learning styles, educator input, and consultation from the student's mentor and university mathematics and statistics department, a textbook or supplement founded in Engineering Education pedagogy would be a welcomed boost in the K-12 movement of integrating engineering.**

Index Terms – Mathematics education, textbook, engineering education pedagogy, STEM, student difficulties in math

BACKGROUND

Shortcomings in Mathematics Textbooks Today

Textbooks have been the common tools in mathematics education for decades alongside the demonstration of practice problems on the board for students to soak up and scribble the same information on the next test. Yet, even the most readily available conduit for enhancing a student's knowledge can go underutilized; this is especially true in the math classroom. Although the author can describe a topic with as much detail and mathematical finesse as he or she chooses, this does not mean the student is invested at all in the material—effectively reducing the text's value as a learning tool to nothing.

Even though instructors expect students to read the textbook outside of class to gain a grasp on the material, students report difficulty not just in comprehension, but reading [1]. For the students without a strong background in mathematics, reading a textbook covering Calculus is similar to learning a second language. In fact, this is more common than educators would hope. Since math does not read as easily as a History or English textbook, students need to develop the ability to read in the mathematical sense. Kilpatrick emphasizes the ideal of "mathematical literacy" and further asserts that such development is best begun early in K-8 [2]. In short, if students are "mathematically illiterate," then traditional methods of textbook writing will fail in communicating necessary information to the reader.

Since students have problems with the reading aspect of a math textbook, one could infer that visual learning can take a prominent role. By deformalizing mathematics and presenting it holistically, students could comprehend the nature of math rather than all of the technicalities associated with certain topics [3]. Perhaps the outcomes assigned to each class need to be reevaluated and determine what exactly is expected of each student upon completing the class [4]. Through this realization, the pedagogy behind a math class can be better defined and, in turn, better communicated.

Textbooks, by their nature, hold all of the information pertaining to a certain subject within the scope of the intended grade level. However, it is ultimately up to the teacher how the text is utilized. Since words like "comprehend" and "understand" are sparse through the Common Core standards, it is a frightening thought that math education could slip all the way back down to the bottom of Bloom's Taxonomy [5,6]. Instead of relying on the teacher to provide an explanation, these textbooks should be able to communicate the message in a way students can understand.

Intertwining Engineering Education Pedagogy within Math Textbooks

Highlighted by two reports, *Rising above the Gathering Storm* and *Standards for K-12 Engineering Education,* a noticeable absence in the acronym, STEM, is apparent in secondary education [7,8]. Engineering has a certain stigma to it, which hinders the effort of integration due to the shortage of faculty knowledgeable enough to teach the subject in a K-12 environment. In some cases, engineering can be misrepresented as something seemingly similar, such as science. Based on the method of grounding students to appropriate examples and speaking at the student's level from an undergraduate Engineering Education student's point of view, a mathematics textbook or supplement is feasible for implementation at the high school level.

METHODS

An undergraduate student majoring in Engineering Education has a goal of writing a mathematics textbook which integrates engineering concepts for high school students. To ensure this project is properly managed, the student will be advised and assisted by the director of Engineering Education to ensure proper engineering examples are included. Also, an advisory board of volunteer teachers will serve as a resource for reviewing text samples, offering ideas, and answering questionnaires relevant to the text. The student will also seek assistance or advice from the university mathematics and engineering departments when appropriate.

INITIAL DISCUSSION

An advertisement of sorts served as the discussion point for the project during a poster presentation that served as a follow up to a previously held teacher workshop (Figure 1). Three teachers, two math and one science, were present along with two professors and four Engineering Education students. After introducing the concept for the book, an open discussion was held in order to gain some initial feedback on whether such a project was necessary.

Initial reactions to the idea were positive and sparked some points to note. One teacher explained the lack of appropriate examples in Calculus textbooks to the effect of, "Everyone uses the water ripple example, but no one even cares because it's never tied to anything." Furthermore, the participant expanded on this point by asserting, "Students are more willing to listen when it has purpose, and in the higher level math classes, it tends to become much more difficult to find that application."

Two teachers explained the lack of concrete standards in terms of higher mathematics—in this case, Calculus. One instructor added, "Typically anything like Calculus is not stressed as much because the students who take it are already done with their math requirements." In fact, the common core standards have no main section or heading for Calculus in the lengthy document, which seems to elevate it to a position of higher mathematics not meant to be included in the opinion of the authors of the standards [5].

One student mentioned the idea of imaginary numbers and how students find it difficult to find an application for something that seems so abstract. This notion students believe would raise the question, "How are there practical uses for numbers that don't even exist?" Yet, once a solid example of their application in electric circuits is given, the knowledge becomes more immediate and necessary, according to the student.

Other methods of collecting teacher opinions were discussed: such as polling, attending math education conferences, and conducting a Delphi study.

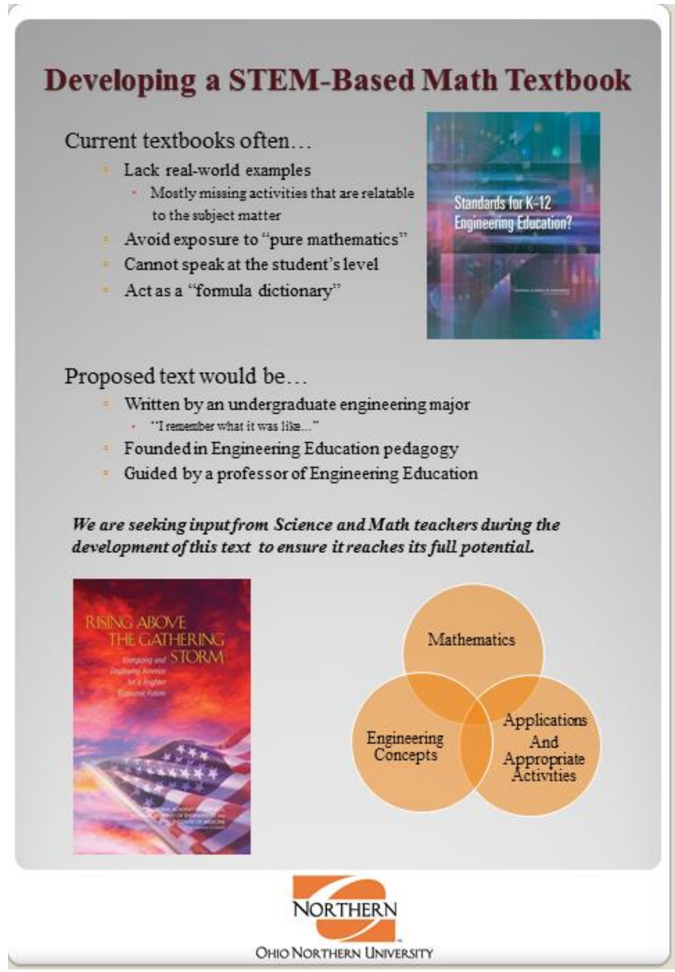

FIGURE 1
"ADVERTISEMENT" TO SPARK DISCUSSION AT THE POSTER PRESENTATION

FORMATION OF THE ADVISORY BOARD

A call for math and science teachers was made public on social media accounts moderated by the Ohio Council of Teachers of Mathematics in May 2013, which invited members to send a note of interest to the investigators. At the time of the first round of questions, teachers representing 10 different schools across 2 states offered to assist in this effort. Even though the study is already in progress, teachers are still permitted to join the project at any time. The advisory board is diverse, with teachers of Algebra, Geometry, Calculus, Statistics, and Physics. With the combined effort of the university's mathematics and engineering departments alongside the advisory board, the text has a strong support system behind it.

IMPLEMENTING A DELPHI STUDY

In order to gain some structure for this project, the investigators proposed to use the advisory board for a Delphi study [9]. Teachers on the board are sent questions and a newsletter with updates on the status of the project in intervals of approximately 3 to 4 weeks. All questions and content are developed by the investigators.

Round I: Developing the Framework

The first round of questions was developed by the investigators to create some idea for what should be targeted by this project in terms of content and market. The teachers were sent these questions:

- What do you envision being covered in this text?
- What topics do your students seem to struggle with? Are there topics that aren't covered as much or as well as you'd like in your current text?
- Would you consider your current text to be underutilized by your students?

From the responses, three concept maps were created to illustrate their answers. Figure 2 organizes all of the comments given for the first question concerning content to be covered in the text. Content conversation from Round I focused mainly on STEM activities, applications of trigonometry, applications in physics and chemistry, and extended problems. Participants voiced concerns over covering too much material and trying to make a text that can be described as a "jack of all trades but master of none." In fact, proposed subjects to be adopted into the text included Calculus, Trigonometry, Statistics, Chemistry, Physics, and Engineering. From the concept map (Figure 2), Round II will narrow down material from the laundry list of concepts to the necessities.

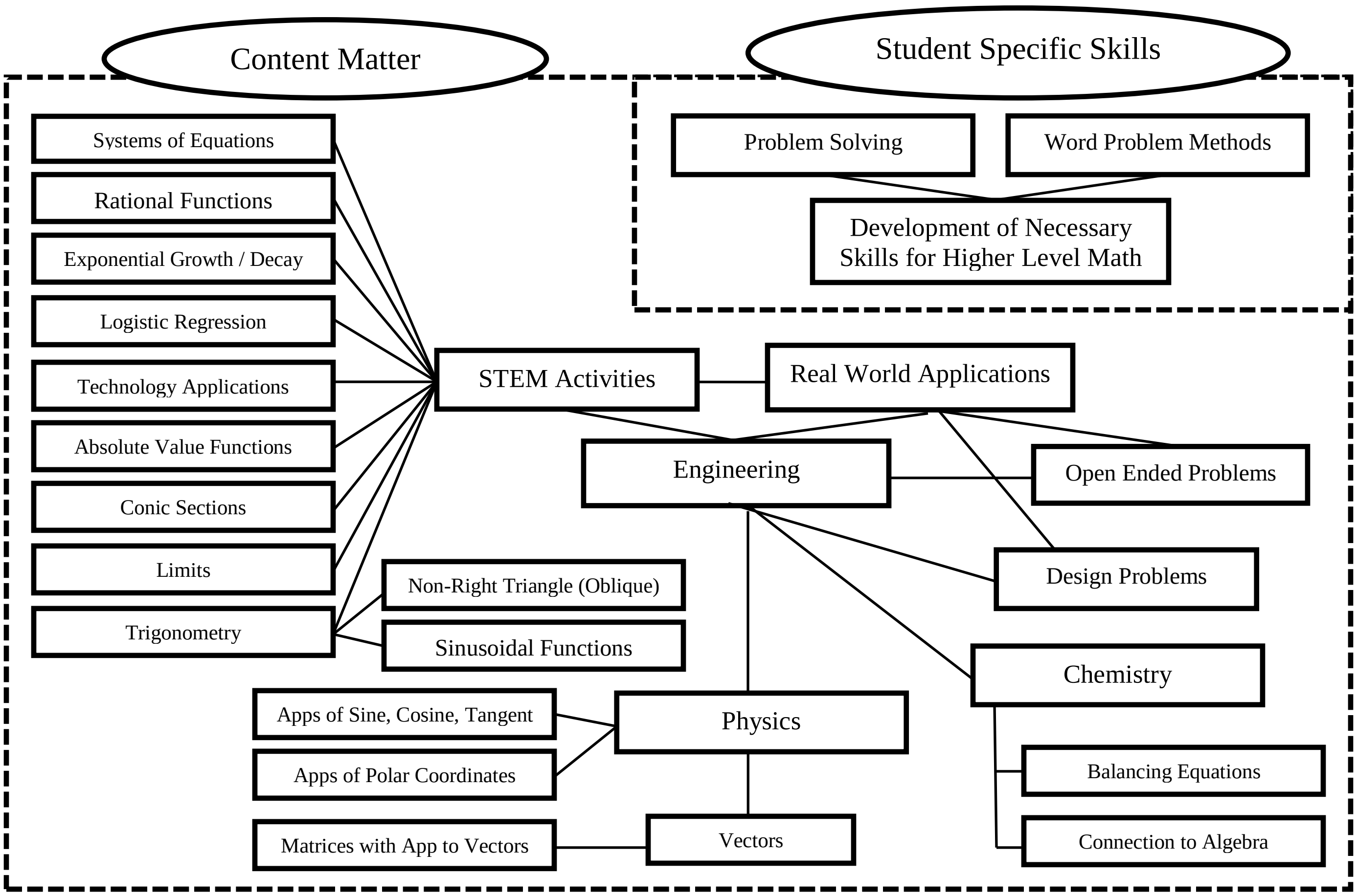

FIGURE 2
FOUNDATION FOR A STEM TEXTBOOK / SUPPLEMENT BASED ON ROUND I RESPONSES

Compared to another proposed layout based on an NSF project to classify first year engineering courses [10], the Round I concept map provides a more targeted audience for the material rather than the general topics covered in Figure 3. The rationale for using the classification scheme stemmed from the idea that each topic listed in the diagram is covered in an "Introduction to Engineering 1" or "Engineering 1" course at different universities— given not every course is comparable [10]. Through this, a student who completes the text will be better prepared to enter into a STEM degree program, particularly engineering. It is possible that both layouts will be utilized to some degree.

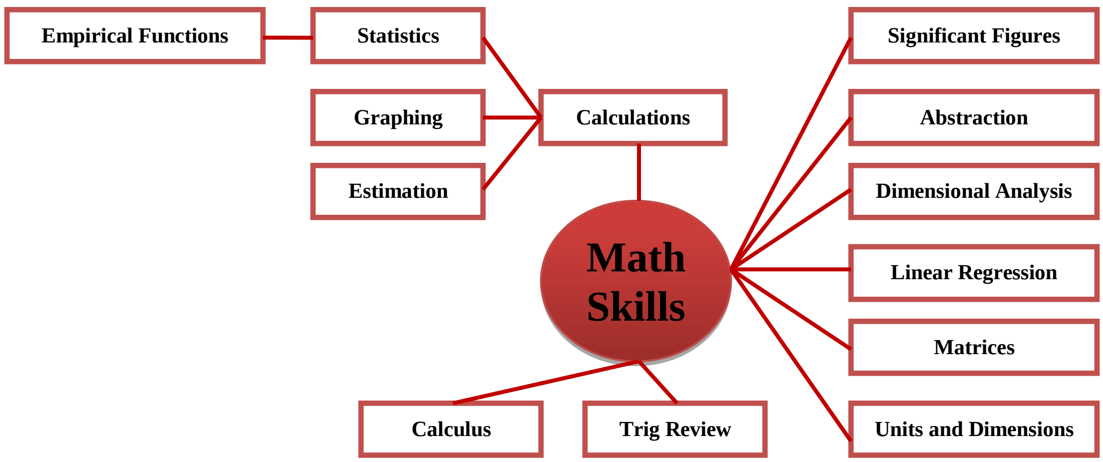

FIGURE 3
FOUNDATION FOR A STEM TEXTBOOK / SUPPLEMENT BASED ON NSF CLASSIFICATION SCHEME [10]

Areas of Interest: Where Are Students Falling Behind?

The second question from Round I asked teachers to list or describe any concept or topic their students seem to have difficulty understanding. Figure 4 provides a general overview of the teachers' responses, but the additional dialogue may give some clarity to a few ambiguous terms represented. In terms of general concepts, simple algebra appeared frequently. Even basic skills like "variable identification" were reported as difficulties. One Physics teacher explained , "It appears that if the equation has a bunch of x's, y's, and z's[,] students have little to no problem solving the equation for an unknown[;] [yet,] as soon as you put in velocity, acceleration, and time symbols, students make mistakes or outright act as though they have no idea how to solve it."

Surprisingly, the advisory board did not focus exclusively on specific topics; instead, most teachers reported problems that would fall under the umbrella of *mathematical perseverance*. One math teacher responded, "Students need to develop mathematical perseverance; students are generally quick to give in when the answer either is not clearly apparent or the route to the answer is viewed as too lengthy." Another teacher reported, "Anything with multiple steps is an issue for my students…when there is a sign change…piece missing… or an extra piece…they just shut down." With this in mind, it is understandable that low student achievement can be directly traced to mathematical perseverance—especially with open ended problems. Still, further work needs to be done to verify the impact of low mathematical perseverance on students' academic achievement. Due to this gap in research, an appropriate project will be run concurrent with the Delphi study involving the advisory board.

Usage of Textbooks

The final question concerned how textbooks are being used, "Would you consider your current text to be underutilized by your students?" Here, the responses split into three distinct strands based on the root of the problem: student, author, and economic (Figure 5).

Student textbook underutilization typically was a result of mathematical illiteracy, unfocused perception of the text, and the existence of a generation gap. One math teacher responded with, "Students struggle to read a math textbook…in my experience, students find it too difficult to read a textbook because it requires more work on their part than other options open to them." In this case, the cause of their inability to read may be placed on the authors for not speaking at the student's level or, more often than not, on the student him or herself. Another teacher commented on the students' perception of the text: "Students don't like to read the text…they only consult the book for homework problems." The existence of a generation gap must also be acknowledged, considering the rise of electronic versions of textbooks. A participant observed that students would rather use the electronic version of the text instead of the traditional hard bound version: "My students *will* use a textbook if they can pull it up on their laptops." Finally, economic factors play a large part in the use of textbooks: "Many school districts lack the funds to have more than a class set of books." In some cases, a teacher from the board cited that some textbooks are being used for classes for which the author did not intend.

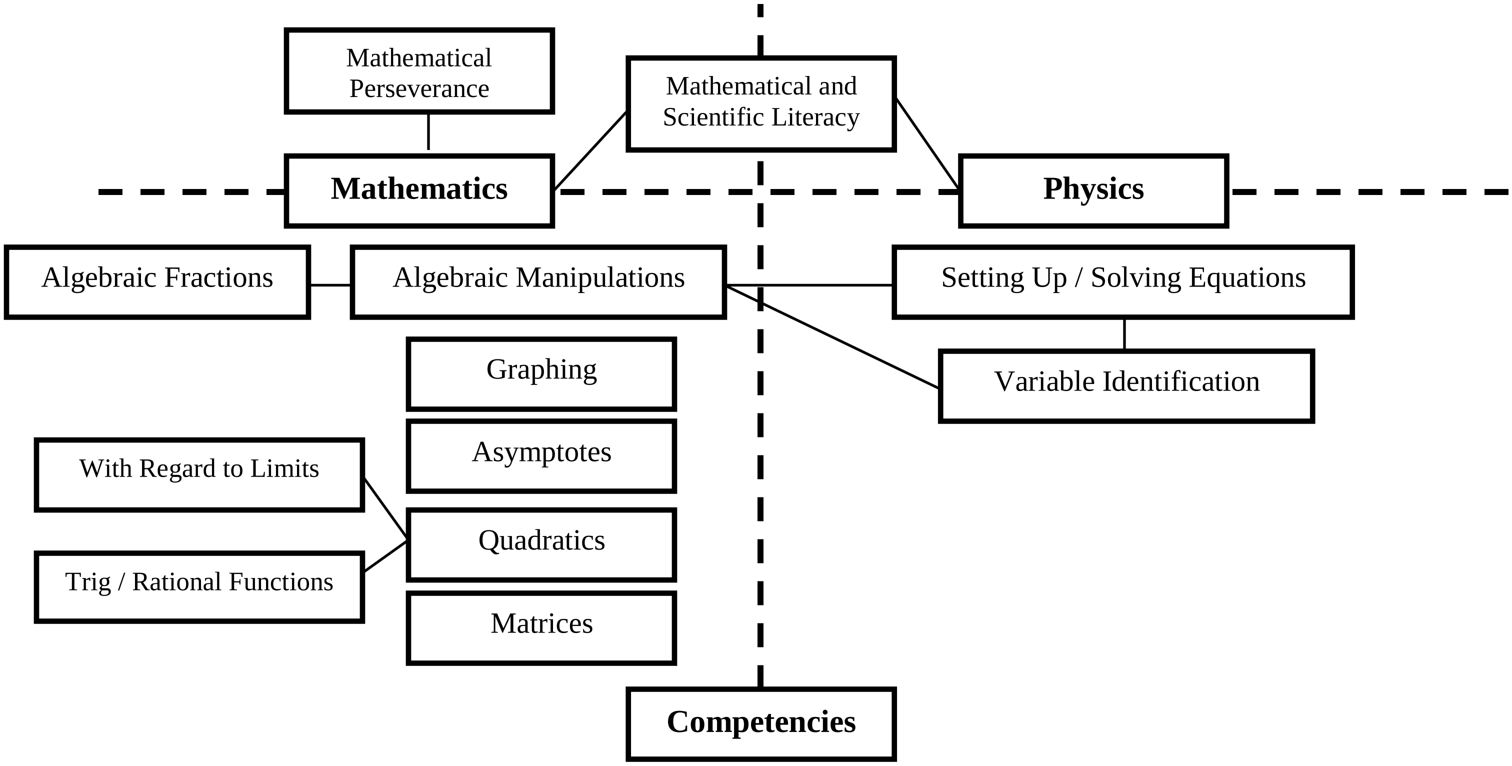

FIGURE 4
OBSERVED STUDENT DIFFICULTIES (ROUND I RESULTS)

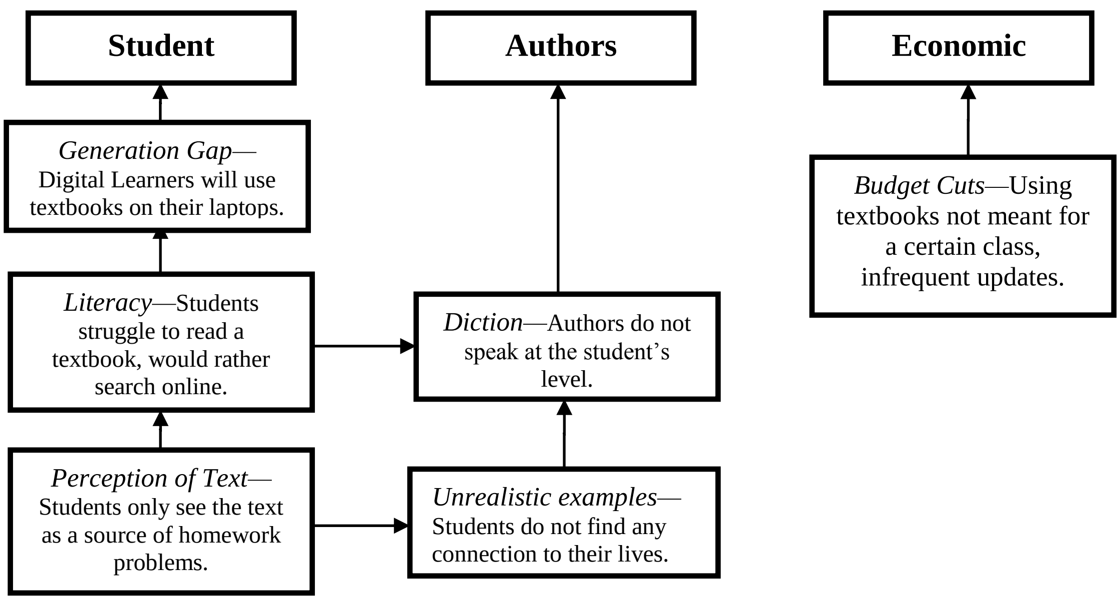

FIGURE 5
REPORTED ISSUES WITH THE USE OF TEXTBOOKS (ROUND I RESULTS)

Round II and III: Refining and Focusing

Round II focuses on verifying the proposed content and student difficulties reported from Round I. The following are the questions sent to the advisory board.

- Please look over Fig. [2], Fig. [4], and Fig. [5]. Do you feel that these are accurately represented? Anything to change?
- If a supplement was the result of this effort, what would be wise to include so it stands out among other published texts?
- What is your definition of an “authentic” math problem?
- How would you describe your teaching philosophy? Similarly, how do you view mathematics/physics in your students’ context? (Is it a tool to encourage critical thinking? Something they just need to know?)

These questions were developed to get a feel for the opinions of teachers in terms of how they conduct their class in the case that this information is significant. Furthermore, Round III and any subsequent rounds of questions will be conducted on the 3-4 week schedule. Results will be discussed in a future paper.

CONCLUSION

The development of a mathematics textbook (or supplement) incorporating authentic examples will contribute to teachers who wish to incorporate engineering into their classroom. To insure the usability and high quality of the final product, this effort uses a teacher focus group to inform the development of this material. While the project is still in its research phase, further interaction with the board of teachers will provide a clearer definition for what the result of this effort will become. It is intended that once a distinct outcome for this initiative is determined, more specific surveys and focused interactions between the board of teachers, university departments, and publishers will increase.

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