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Engineering in the Equation: Comparing Mathematic Problems to Engineering Practice

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Engineering in the Equation: Comparing Mathematic Problems to Engineering Practice (Fundamental)

Abstract

As the demand for engineers continues to increase, the need for K-12 students understanding of engineering becomes more important. This research explored the alignment between engineering problems designed for high school mathematics students and real-world engineering work. Using a mixed-methods approach, the study combined quantitative analysis of an Engineering Profession in Mathematics (EPM) questionnaire with qualitative data from interviews with engineers, engineering professors, and mathematics teachers.

While no statistically significant differences were found between participant groups for the 24 engineering problems evaluated, qualitative interviews provided valuable insights. Five specific engineering problems were selected based on their mean scores from the EPM questionnaire for in-depth discussion during interviews. Two problems received unanimous approval from all interviewees: an analysis of Great Lakes water levels and an aircraft fuel calculation considering wind conditions. These problems were seen as representative of typical engineering work. Engineers and engineering professors generally viewed the selected problems favorably, with one exception. However, mathematics teachers expressed concerns about the complexity and relevance of some problems for their students, highlighting a potential disconnect between academic exercises and real-world applications.

The study emphasized the critical role of mathematical content in developing analytical and problem-solving skills essential to engineering. However, applying mathematics in real-world contexts emerged as even more crucial than specific content knowledge. Participants consistently stressed the importance of problem-solving abilities, asking appropriate questions, and being comfortable with uncertainty. Current educational practices, particularly standardized testing, were identified as potential barriers to developing students' creativity and real-world problem-solving skills. This suggests a need for educational approaches that foster open-ended thinking and comfort with ambiguity, characteristics of engineering work.

In conclusion, while there is general alignment between engineering problems in high school mathematics and real engineering work, room for improvement remains. By emphasizing problem-solving, questioning, and comfort with uncertainty in mathematics education, educators can better prepare students for potential engineering careers and provide a more authentic representation of the field. This approach not only serves future engineers but equips all students with valuable skills applicable across various disciplines and real-world scenarios.

Introduction

According to the United States Bureau of Labor Statistics [1], the demand for engineers is expected to grow by 10% between 2022 and 2032, underscoring the increasing need for skilled professionals. However, despite the growing demand, many students, teachers, and parents struggle to understand what engineering entails. This lack of understanding poses a challenge in guiding students toward pursuing engineering as a potential career path, particularly when the foundation for this discipline is rooted in complex mathematical and scientific principles [2].

Although mathematics is foundational to engineering, it is often treated as supplementary or an enrichment activity within K-12 engineering curricula [2]. Roehrig et al. [3] highlight the need for further research on the role of mathematics in STEM education, particularly regarding its integration with engineering. Current curricula and professional development initiatives often fail to integrate mathematical analysis and modeling in a way that reflects its central role in engineering problem-solving [2, 4, 5]. This gap in instruction suggests that K-12 students may not fully understand how mathematical reasoning underpins engineering design, which limits their ability to develop critical problem formulation skills [6].

To effectively prepare students for the challenges of engineering careers, it is essential to integrate problem-solving and analytical skills into the K-12 mathematics curriculum. As defined by the National Academies [7], engineering education revolves around real-world applications of scientific principles through an iterative problem-solving process. However, despite its growing emphasis in K-12 education [8], engineering remains a relatively new discipline in schools, and many mathematics educators struggle to integrate engineering content meaningfully due to a lack of interdisciplinary guidance in the Common Core State Standards for Mathematics (CCSSM) [9].

This research seeks to address the gap in the integration of engineering and mathematics by identifying the types of mathematics and engineering problems that may best represent the engineering profession. Specifically, the study explores how high school mathematics teachers, engineering professors, and practicing engineers perceive the mathematics used in real-world engineering problems. The primary research question is: *How do current engineering problems designed for high school mathematics students compare with the work that engineers perform?*

This study aims not to propose a new engineering mathematics curriculum but to explore how existing K-12 mathematics courses can be enhanced by integrating real-world engineering principles. By fostering students' understanding of mathematics as it applies to engineering, the study hopes to provide them with a clearer understanding of career opportunities in engineering and help develop the problem-solving skills essential for success in the field [10, 11].

Literature Review

Engineering as a Profession

Mathematics plays a complex and sometimes ambiguous role in the engineering profession. Contrary to common expectations, many practicing engineers claim that advanced mathematics is not integral to their daily work [12, 13, 14]. In their interviews and observations of civil and structural engineers, Kent and Noss [13] found that, while they anticipated engineers would explicitly reference complex mathematical practices, many engineers indicated that they rarely used the advanced mathematics learned during their formal education. Instead, they relied on computational tools to handle complex calculations in engineering design. Kent et al. [15] later characterized this phenomenon as *techno-mathematical literacy* (TmL), a concept that encompasses mathematical, information technology (IT), and workplace-specific competencies needed to interpret abstract information and make informed decisions. TmL suggests that using mathematics in engineering is more about understanding the significance of computations than performing hand calculations.

Despite the diminished role of manual calculation in engineering practice, mathematics remains crucial in fostering the analytical thinking required for effective engineering design. Kent and Noss [13] noted that the use of mathematics shifts over the course of an engineer's career. While early-career engineers may rely on calculations to understand and execute designs, more experienced engineers primarily use mathematical understanding to inform their design decisions. One senior engineer explained that serious hand calculations are primarily conducted by those within two or three years of graduation or by lifelong analytical specialists [13].

Furthermore, there is a distinction between the objectives of engineers and mathematicians. Engineers apply mathematical concepts to solve real-world problems and design solutions, whereas mathematicians emphasize structure, rigor, and theoretical development [12]. In this sense, engineering education often prioritizes applying, interpreting, and manipulating mathematical models, while mathematicians focus on formalized mathematical modeling for theoretical exploration. Bissell and Dillon [12] proposed a hierarchical model for engineers working with mathematical models: engineers must first interpret the model's meaning before manipulating it to solve problems. Ultimately, the goal for engineers is not simply to solve mathematical equations but to understand and predict the behavior of complex systems. Thus, while advanced mathematics may not be a routine part of engineering practice, its role in developing logical, analytical thinking skills remains essential [14]. Kent and Noss [13] highlight the challenge for engineering education, noting that it is not solely about increasing the quantity of mathematics taught but addressing the interface between engineering and mathematics knowledge, as experienced by students and practicing engineers.

Engineering in Post-Secondary Education

In post-secondary engineering education, students' primary goal in learning mathematics is to apply mathematical techniques and skills within their engineering coursework and future professional practice [4, 16]. First-year engineering students often view mathematics as a subject of study in its own right and a practical tool for solving engineering problems [17]. However, many students experience a gap between their expectations of mathematics in engineering and the reality of its application in academic and professional contexts [18]. Students who report challenges in their engineering courses suggest that integrating discipline-specific examples of mathematics into engineering lessons would improve their perceptions of the program and its real-world applicability [19].

Flegg et al. [20] recommend that mathematics instructors explicitly demonstrate the relevance of mathematical concepts for engineering students, particularly through problem-solving tasks that are grounded in real-world engineering applications. In this context, the European Society for Engineering Education (SEFI) developed a framework outlining eight key competencies for learning mathematics in engineering education [21]. These competencies include reasoning mathematically, posing and solving mathematical problems, mathematical modeling, and using mathematical tools effectively. This framework builds on the work of Niss [22], who identified essential mathematical competencies to transition from secondary to university-level mathematics.

Engineering in Pre-Tertiary Education

In K-12 education, the integration of engineering and mathematics is often fragmented, with both subjects typically treated as distinct rather than interrelated [2]. Although engineering has been incorporated into the Next Generation Science Standards (NGSS) [7], mathematics education has not formally integrated engineering into the CCSSM [9]. Gamboa et al. [23] observed that many STEM educational initiatives position mathematics as a supportive tool for science and engineering rather than an integral part of the engineering process.

The K-12 Engineering Framework, developed by the Advancing Excellence in Pre-School to Twelfth Grade Engineering Education initiative and the American Society for Engineering Education [24], identifies several key mathematical topics relevant to engineering, including Engineering Algebra, Geometry & Trigonometry, Engineering Statistics & Probability, and Engineering Calculus. While the framework describes the connection between engineering and various areas of mathematics, it does not offer clear guidance on integrating the two fields within K-12 curricula.

Despite these challenges, some engineering curricula have successfully integrated mathematics and science to demonstrate their real-world applications [25]. For example, research has shown that engineering education can enhance middle school students' confidence in mathematics and foster interest in engineering careers [26]. Redmond et al. [26] conducted a study with over 1,200 sixth and seventh-grade students participating in an engineering program called *Get a Grip*. Their findings indicated a statistically significant increase in the students' confidence in mathematics and science after participating in the program, compared to a control group. This highlights the potential benefits of integrating engineering principles into K-12 mathematics education to enhance student engagement and career awareness.

Intersection of Engineering and Mathematics Practices

While the integration of engineering and mathematics in K-12 education has been underexplored, there has been growing interest in integrating STEM disciplines more broadly

[27, 28, 29, 30]. Both science and mathematics have their own sets of practices, as defined by the NGSS [7] and the CCSSM [9]. However, engineering has not yet been systematically incorporated into the mathematics practices. There is, however, a growing recognition that mathematical modeling is an authentic representation of engineering work [31].

The CCSSM outlines key mathematical practices, emphasizing problem-solving and mathematical modeling [9]. These standards are designed to deepen students' understanding of mathematical concepts. Yet, they do not address the integration of engineering practices, which can be challenging when connecting mathematics to real-world engineering problems. This gap may contribute to the difficulties that educators face in effectively integrating engineering practices into mathematics instruction.

Simarro and Couso [32, p. 7] proposed a set of revised engineering practices that could better support student learning in the intersection of engineering and mathematics. These practices include "defining and delimiting engineering problems," "developing and using prototypes and simulations," and "analyzing and interpreting data to identify points for improvement." These revised practices offer a more comprehensive view of engineering design, including the consideration of constraints, optimization, and iterative problem-solving—central elements of the engineering process. While the NGSS [7] incorporates engineering practices, it omits key concepts such as constraints, which are essential to understanding engineering design [33].

The revised engineering practices proposed by Simarro and Couso [32] provide a more comprehensive framework for integrating engineering into the classroom, particularly in K-12 education. Stage et al. [34] and Marco-Bujosa [35] have explored the intersections between mathematics, science, and engineering practices. Their work demonstrates how common practices, such as model development, can bridge the gap between disciplines, ensuring that students understand how mathematics and engineering are interconnected in real-world contexts.

Conceptual Framework

The conceptual framework for this research focuses on the dynamic relationship between educational engineering problems and professional engineering practice, mediated through mathematical content and pedagogical considerations. This theoretical structure guided the development of the Engineering Profession in Mathematics (EPM) questionnaire and interview protocols, enabling the research to systematically examine how current engineering problems designed for high school mathematics students align with actual engineering work, while considering both educational effectiveness and professional authenticity.

Methods

Research Design

An explanatory sequential mixed-methods design was employed in this study to explore the types of mathematical and engineering problems that teachers and engineers perceive as representative of engineering practice [36]. The explanatory sequential design follows a two-phase approach: a quantitative phase followed by a qualitative phase. In the first phase, the researcher conducted a quantitative survey using the Engineering Profession in Mathematics (EPM) questionnaire to identify significant, nonsignificant, surprising, and confusing results [36]. In the second phase, qualitative interviews were conducted to investigate further and provide in-depth insights into the findings from the quantitative phase. This two-phase approach enabled a comprehensive understanding of the research questions by combining the strengths of both quantitative and qualitative methodologies. While the initial phase provided a broad quantitative analysis, the qualitative phase was designed to explore the nuances of the findings, offering a deeper understanding of the phenomenon under investigation.

Several studies in STEM education have successfully employed the explanatory sequential mixed-methods design (e.g., [37, 38]). For example, Hammack and Ivey [39] surveyed over 500 public school teachers and conducted focus groups to explore elementary teachers' perceptions of engineering and engineering design. Similarly, Gasiewski et al. [40] gathered quantitative data from over 2,500 students and conducted focus groups with 41 students to investigate the relationship between student engagement and introductory science instruction.

Instrumentation

The Engineering Profession in Mathematics (EPM) questionnaire was developed to assess the types of mathematics used in engineering practice. The questionnaire provides a common structure for evaluating engineering problems based on their alignment with mathematical content standards. The 24 engineering problems in the questionnaire were derived from pre-service teachers' lesson plans for grades 7-12, and these problems were categorized into eight mathematical content areas. The problems were selected using a two-stage evaluation process that considered real-world relevance and pedagogical alignment, emphasizing engineering problems over abstract mathematical content [41].

The target population for this questionnaire included K-12 mathematics teachers, engineering professors, and practicing engineers. The EPM questionnaire, a one-time-use tool, was designed to include eight mathematical content standards (e.g., statistics, proportional relationships, functions) and 24 engineering problems aligned with these standards. The respondents were asked to evaluate whether specific mathematics was used in each problem, categorizing their responses as follows: (1) "Yes, engineers use this," (2) "Sometimes, engineers use this," or (3) "No, engineers do not use this." Additionally, respondents were asked to determine whether the engineering problem involved specific mathematical content, with categories (1) "Yes, with the mathematical content," (2) "Yes, but with a different process," or (3) "No, engineers would not solve this type of problem." The responses were used to generate ordinal data, and a total raw score was computed based on the sum of mathematics content and engineering problem categories. The EPM questionnaire was structured to separate mathematics and engineering items, and the analysis was exploratory.

Qualitative Study

The qualitative phase of the study involved in-depth interviews with engineers, engineering professors, and mathematics teachers to explore their perceptions of the relationship between engineering problems and mathematical content. The EPM questionnaire served as a basis for developing the interview protocol, allowing for a more detailed discussion of the mathematical concepts and problem-solving approaches participants identified as relevant to engineering practice.

The interview protocol was structured to allow participants to respond to general questions as well as role-specific questions that reflected their professional backgrounds. Interviews were conducted virtually using Microsoft Teams, and participants were provided with the protocol in advance. Each interview lasted between 45 and 75 minutes, was transcribed using Microsoft Teams, and verified for accuracy within 48 hours. The qualitative data were analyzed using a grounded theory approach, incorporating open and selective coding procedures. The constant comparative method was employed to ensure that the researcher identified patterns and themes inductively from the data [10]. The researcher analyzed the interview transcripts in the open coding phase without imposing pre-existing interpretations. In the selective coding phase, the researcher organized open codes into theoretical categories that addressed the research questions. To maintain the validity of the findings, the interview transcripts were anonymized, and gender-specific pronouns were made plural. Direct quotes were preserved to ensure accurate representation of participants' views, while filler words were omitted to maintain clarity and readability.

Data Analysis

Quantitative data collected from the EPM questionnaire were analyzed to identify how engineering problems align with the type of work engineers perform. In particular, responses from participants were examined to determine whether engineers would solve specific problems using the identified mathematical content.

To test for homogeneity of variance, the researcher conducted Analysis of Variance (ANOVA) tests using the Levene statistic. The results indicated violations of the assumption of homogeneity of variance and normality in several comparisons. In these cases, Welch's ANOVA was used to account for these violations, as it is less sensitive to skewness in data and does not assume homogeneity of variance for unequal group sizes with at least ten observations [42, 43]. For ANOVA tests that yielded significant results, Tukey's post hoc tests were conducted for pairwise comparisons. When Welch's ANOVA indicated significance, Games-Howell's post hoc tests were used, as this method assumes unequal variance between groups.

To mitigate the risk of a Type I error (false positive) due to multiple comparisons, the researcher applied [44] adjustment procedure for p-values. This procedure reduces both Type I and Type II errors compared to the more commonly used Bonferroni correction [45].

Qualitative Interviews

The research question was explored through semi-structured, individual, in-depth interviews for the qualitative analysis. The researcher, who served as both the primary data collector and analyst, employed an inductive approach to produce richly descriptive findings [46]. The interviewees were selected based on the results from the EPM questionnaire. Purposeful sampling, a non-probabilistic technique, was used to identify participants with expertise in the areas most relevant to the study [47].

A total of 22 participants were identified as willing to participate, with 20 agreeing to be interviewed. Of these, six interviews were conducted with a diverse group of participants: two practicing engineers, two math teachers with engineering backgrounds, one engineering professor, and one practicing engineer with extensive teaching experience. The interview participants' demographics are shown in Table 1.

Table 1
Interview Participants Demographics

				Years working in field			
Interview Identifier	Gender	Profession	Discipline	Engineer	Math Teacher	Engineering Professor	Education
MT1	F	MT E	Civil	1-5	11-15		Masters
MT2	M	MT E	Logistics	11-15	21-25		Masters
E1	M	E	Computer	> 26			Bachelor
E2	M	E	Electrical	> 26			Masters
P1	M	P	Mechanical			21-25	PhD
PE2	M	P E	Industrial	21-25		6-10	Masters

Trustworthiness in qualitative research is assessed through four key criteria: credibility, dependability, transferability, and confirmability [48, 49, 46]. The researcher employed triangulation of participants (E, MT, and P) to ensure credibility and provided rich, thick descriptions of participants' perspectives. Dependability was maintained using an audit trail documenting the data collection and analysis process. Transferability was ensured by aligning the study with established research in the field, while confirmability was supported by member checking and peer review. Participants were provided the opportunity to review their interview transcripts to confirm the accuracy of their responses, and a PhD candidate conducted a peer review of the qualitative data coding process to ensure consistency in findings.

Findings

This section is to answer the research question: How do current engineering problems designed for high school mathematics students compare with the work that engineers perform? With the six interviews, the researcher asked each participant about five engineering questions. These five questions were chosen based on their means (Table 2). While identifying the research questions, there was a natural break between Linear Quadratic Exponential (LQE)1 (M=1.24) and Functions 2 (M=1.41) in the total column. The identified questions are in Table 3.

Table 2
Results from the EPM Questionnaire, Lowest six Engineering Questions Means

	Professor	Math Teacher	Engineer	Total
Functions 3	1.25	1.20	1.04	1.16
AV* 3	1.27	1.04	1.25	1.18
Statistics 4	1.05	1.38	1.09	1.19
Functions 1	1.30	1.25	1.17	1.24
LQE** 1	1.14	1.23	1.35	1.24
Functions 2	1.45	1.48	1.30	1.41

Note: * Area and Volume, ** Linear Quadratic Exponential

Table 3
Five Engineering Problems Discussed with Interviewees

Question Code	Question
AV* 3	Construct a container in which water can be transported from a nearby well back to their house
Functions 1	Construct and identify a wind turbine that provides the most power output for the least amount of wind speed provided
Functions 3	Each plane can only fly for 8 hours before running out of fuel. Using both given data as well as data that will be collected, students must determine if the plane will have enough fuel to make the flight, given a certain amount of headwind/tailwind
LQE** 1	Calculate the percent change needed in order to meet renewable energy goals and the percent rate needed to meet them by a certain date
Statistic 4	Analyze water levels through four tables of data relating to water levels of Lake Erie, Michigan-Huron, Superior, and Ontario over the course of 12 months (2019)

Note: * Area and Volume, ** Linear Quadratic Exponential

The researcher gave the interviewees the problems before the interview and posted them in the Microsoft Teams chat for review during the interview. The interviewees' responses were recorded in Table 4, indicating whether they thought the problems were good engineering problems or not. The following is a summary of the interviewees' comments.

Table 4

Pre-Service Teachers Engineering Problems Interviewees identified as being used

	AV3	Function 1	Function 3	LQE 1	Statistic 4
E1	Yes*	Yes	Yes	Yes*	Yes
E2	Yes	Yes	Yes	Yes	Yes
MT1	No	No	Yes	No	Yes
MT2	No	No	Yes	Yes**	Yes***
P1	Yes	Yes	Yes	Yes	Yes*
PE2	No	Yes	Yes*	Yes	Yes

Note: * with modification; ** for a specific class; *** with math content modification, E is engineer, MT is Math Teacher, P is professor, and PE is professor and engineer. AV is Area and Volume, LQE is Linear Quadratic Exponential

Area Volume (AV) 3 Problem

The engineering problem created by a mathematics PST is constructing a container where water can be transported from a nearby well back to their house. E1 read the problem and immediately modified it to be about low bridges. E1 shared an experience when they were on a bicycle, "I ride up to the actual bridge, and there's a semi-truck that looks like a can of tuna … the top of it had just been pulled completely off and … was stuck on the bridge still." E1 thought there was a lot to the question; for instance, you could elaborate and ask, "Why are pop bottles round." P1 identified this as an excellent design problem. E2 said this would be a good problem for Computer Aided Design (CAD).

MT1, MT2, and PE2 did not like the problem. MT2 thought it was unclear, "with the first one (statistics 4), I saw how I would do it and how I would help other kids with it. This one isn't really clear to me; what is it doing without some clarification?" PE2 thought the problem was a little simple, "unless you're talking about material science and that kind of engineering. You know, or machining or something of that nature. I don't see that as an engineering problem."

Function 1 Problem

The engineering problem created by a mathematics PST is to construct and identify a wind turbine that provides the most power output for the least amount of wind speed provided. P1 and PE2 thought the problem was good for engineering. P1 and PE2 discussed trade-offs as a key feature of the problem. P1 suggested that students would need to consider items such as weight and size. PE2 expanded on the idea of trade-offs,

"you can (make) a wind turbine that is this heavy and requires this much footing and has this much diameter of blade, or you could do this one with different parameters. Which is the better if given a certain set of functional data provided like wind speed, normal allies and range, things like that?"

While saying the problem sounded fun, E1 stated, "I don't know the math that would go on there." MT1 and MT2 brought up challenges with students' understanding of the problem. MT2 identified that it has a lot of physics, "I don't know how you construct a wind turbine that provides power... Seems too hard to me. Again, … we're still talking about high school students, right?" MT 1 stated, "Kids don't understand power output for the least amount of wind provided. That's way too much for my kids."

Function 3 Problem

The engineering problem created by a mathematics PST is: Each plane can only fly for 8 hours before running out of fuel. Using the given data and the data that will be collected, students must determine if the plane will have enough fuel to make the flight, given a certain amount of headwind/tailwind. Everyone liked this problem. MT1 stated this would be a good problem for systems of equations, "I don't think planes use their fuel on a linear basis, right? Because when it's heavier, it costs, it takes more fuel. So, I mean, that would be an interesting problem." MT2 said, "I'd want a little clarification about what the impact of a headwind or tailwind actually is. Are they going to be giving a range for the possible boost or deceleration that order resolved? But I like that problem". PE2 compared it to the "train left the station" kind of problem, a "word problem in algebra. So, it may be a little simple for some people, but it certainly could be used as is or dressed up a little bit."

P1 suggested that students use vectors to solve the headwind and tailwind problem. "Yeah, that you could incorporate something about, you know the angle of the wind as it changes, right? What happens? Those kinds of things you could have … moving up and down a slope." MT2 said that with modifications, you can make it easier or more challenging, "if you just give me the speed up or slow down, this becomes a really easy problem. But if I get to find that on my own, then it becomes a really, really challenging problem." E1 found the question interesting. To make it more interesting, E1 suggested this problem, "I can only fly for four hours before I run out of gas. I'm trying to get somewhere. What's the best route to get there? Or something in there that's actually (a) hard problem."

Linear Quadratic Exponential (LQE) 1 Problem

The engineering problem created by a mathematics PST calculates the percent change needed to meet renewable energy goals and the percent rate required to meet them by a specific date. E2 thought it was a good problem and compared it to government regulations on gasoline and the lack of regulations on electric vehicles. Developing those regulations would require functions. MT2 stated concern about teaching it in class,

"Unlike the other one (statistics 4), where I could see just where you would get the data, you need a lot more, like breaking it down into this much energy in this sector, and this much in this sector, and this much in this sector in order to turn it into like a linear equation. And I like that problem."

P1 suggested the problem be a difference equation, "what percent change do I need year after year in order to meet a goal?"

While E1, E2, P1, and PE2 saw this as an engineering problem, MT1 asked, "What does that have to do with functions?" E1 stated, "That is not the way I would solve that kind of problem." MT2 suggested that, while it is a good problem, it would be better for pre-calculus or Algebra II, not for MT2's geometry students.

Statistics 1 Problem

The engineering problem created by a mathematics PST is to analyze water levels through four tables of data relating to water levels of Lake Erie, Michigan-Huron, Superior, and Ontario over the course of 12 months (2019). P1 and E1 identified the problem by looking at the water level change over a year. E1 said,

"I can see that being an interesting problem that would help me understand why I would take average. I think the water is really high in Toledo today. Is it unusual for it to be that high in May? … What was the average height in May? And is it worse than average? Or is it just that is in May? So it might be the highest that's been all year, but is it always high in May is what I want to know."

E1 and P1 stated that civil engineering would be a good tie-in, and PE2 suggested hydrologists. E2 suggested relevance to climate change.

MT2 modified the mathematical content for the problem. Using surface area and volume, MT2 considered it an area and volume problem. "What is the surface area and then what's the volume that it would take in order for it to drop by that amount? I think it's a really cool problem."

Summary

The researcher used an explanatory sequential mixed-methods design to answer the research question: how do current engineering problems designed for high school mathematics students compare with the work engineers perform? When evaluating the 24 engineering problems from the EPM questionnaire, no statistical significance was found between the participants for any of the problems. The mean for the summation of participants was used to identify engineering problems for the interviews. The five engineering questions used are in Table 3. Of the five questions, all six participants agreed on two questions:

- Statistics 4 - Analyze water levels through four tables of data relating to water levels of Lake Erie, Michigan-Huron, Superior, and Ontario over the course of 12 months (2019)
- Function 3 - Each plane can only fly for 8 hours before running out of fuel. Using both given data as well as data that will be collected, students must determine if the plane will have enough fuel to make the flight, given a certain amount of headwind/tailwind.

The engineers and engineering professors thought all of the engineering questions and the alignment with the suggested mathematics content were good questions, except one. PE2 thought the AV3 problem, constructing a container in which water can be transported from a nearby well back to their house, was too simple.

Results

The analysis of engineering problems in high school mathematics revealed complex patterns in how different professionals perceive and evaluate engineering-based mathematical tasks. Through this mixed-methods approach, the researcher identified key findings about the integration of engineering problems into mathematics education, with both quantitative and qualitative results illuminating different perspectives.

Quantitative Analysis

Initial analysis of the Engineering Profession in Mathematics (EPM) questionnaire responses showed no statistically significant differences (Table 2) between engineers, engineering professors, and mathematics teachers in their evaluation of 24 engineering problems ($p > .05$). This suggested broad agreement on the surface level about what constitutes engineering work. This finding aligns with prior research that suggests consensus among educators and professionals on the importance of mathematical literacy in engineering [2, 4]. However, subsequent qualitative investigation revealed more nuanced perspectives about implementation and authenticity. Roehrig et al. [3] also found similar patterns in STEM integration, highlighting the discrepancy between theoretical alignment and practical classroom application.

Problem Evaluation Patterns

From the questionnaire data, we identified five problems for in-depth investigation through semi-structured interviews. Two problems emerged with universal acceptance across all participant groups. The first involved analyzing water levels across four Great Lakes over a 12-month period. This problem garnered support for its integration of statistical analysis with real-world applications. As one engineering professor noted, "This represents the kind of data analysis engineers regularly perform when evaluating environmental systems." This aligns with findings from the literature on the importance of data modeling in engineering [11], which emphasizes the role of mathematical modeling in solving environmental engineering challenges.

The second universally accepted problem focused on airplane fuel calculations considering headwind and tailwind conditions. This problem's strength lay in its scalability, as one mathematics teacher explained: "If you just give me the speed up or slow down, this becomes a really easy problem. But if I get to find that on my own, then it becomes a really, really challenging problem." This suggests that problems designed for educational contexts should be adaptable to different levels of student proficiency while maintaining the core engineering concepts [50].

Professional Perspective Variations

While quantitative data suggested agreement, qualitative analysis revealed distinct professional viewpoints. Engineers and engineering professors consistently evaluated problems through the lens of professional practice. One engineer stated, "These problems reflect the kind of analytical thinking we use daily." In contrast, mathematics teachers prioritized pedagogical considerations, frequently raising concerns about student readiness and curriculum alignment. This tension between professional authenticity and pedagogical feasibility has been noted in previous studies [2, 13], where researchers found that educators often struggle to implement engineering-based tasks due to concerns over student comprehension and curriculum constraints.

For example, when evaluating a wind turbine design problem, an experienced engineer noted its authenticity to the field, while a mathematics teacher observed, "Kids don't understand power output for the least amount of wind provided. That's way too much for my kids." This dichotomy emerged repeatedly across different problems. Roehrig et al. [3] similarly found that teachers often face challenges when integrating authentic engineering problems into classrooms, particularly when the problems require advanced domain knowledge or mathematical concepts that students have not yet mastered.

Implementation Considerations

Our analysis revealed a significant gap between theoretical problem design and classroom implementation. Mathematics teachers consistently identified three primary concerns:

- **Student Preparedness**: Problems often require prerequisite knowledge beyond typical grade-level expectations. This finding is consistent with research by Pepin et al. [51], which notes that a key barrier to integrating engineering into K-12 mathematics education is ensuring students possess the necessary mathematical skills and prior knowledge.
- **Curriculum Integration**: Teachers expressed challenges in aligning engineering problems with required mathematical standards. As Katehi et al. [2] highlight, while mathematics and engineering are closely intertwined in professional practice, K-12

curricula often fail to reflect this integration, leaving teachers unsure how to incorporate engineering into mathematics lessons effectively.

- **Time Constraints**: Complex engineering problems require more instructional time than traditional mathematics problems. This aligns with findings by Moore et al. [12], who argued that the time demands of project-based learning and interdisciplinary curricula often conflict with the rigid pacing required in standardized K-12 education systems.

Problem Adaptability

A key finding emerged regarding the importance of problem flexibility. Participants from all groups suggested modifications to enhance educational value and engineering authenticity. For instance, when discussing the water container construction problem, one engineering professor suggested incorporating material science concepts, while a mathematics teacher proposed simplifying the initial parameters for student accessibility. This adaptability proved crucial for bridging the gap between professional engineering practice and educational requirements. As one participant noted, "The best engineering problems can be scaled up or down while maintaining their core mathematical concepts."

Conclusion

Developing effective engineering problems for mathematics education presents a complex challenge that requires careful consideration of multiple interconnected factors. This research demonstrates that successful problem design must achieve a delicate balance across several key dimensions to meet both educational and professional requirements.

First, professional authenticity emerges as a critical component in problem design. Engineering problems must accurately reflect the practices, thought processes, and real-world challenges in professional engineering contexts. This authenticity ensures that students engage with genuine engineering methodologies rather than simplified approximations that may fail to develop necessary professional competencies [6].

However, this professional authenticity must be carefully balanced against educational accessibility. Engineering problems must remain within the cognitive and mathematical capabilities of the target student population. Problems that exceed students' current mathematical understanding or prerequisite knowledge may impede rather than enhance learning outcomes, regardless of their professional relevance [52].

The ability to adjust the problem to different difficulty levels is another consideration in problem design. This research indicates that effective engineering problems should incorporate multiple levels of complexity. This layered approach allows instructors to adjust problem parameters and requirements to accommodate varying student abilities and course levels while maintaining the core engineering principles taught [51].

Perhaps most critically, this analysis reveals the importance of clear mathematical connections within engineering contexts. The researcher found that engineering scenarios must explicitly and transparently link to the mathematical concepts intended to reinforce. Without these clear connections, students may struggle to transfer mathematical knowledge between pure and applied contexts, potentially compromising their engineering and mathematical development [2].

These findings suggest that while creating engineering problems that satisfy educational and professional standards presents significant challenges, it is achievable through careful attention to these key factors. The widespread adoption and success of specific problems across various educational contexts indicates that this balance between pedagogical needs and engineering authenticity can be successfully achieved. However, careful consideration of multiple stakeholders' perspectives is required throughout the design process.

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