School Science and Mathematics

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Integrating Math and Science Through Engineering: Illustrative Examples From Curricula Implementation in Middle School Engineering Classrooms

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ABSTRACT

Engineering has emerged as a promising context for STEM integration in K-12 schools. In the previous decade, the field has seen an increase in curricular resources and pedagogical approaches that invite students to utilize mathematics and science as they engage in engineering practices. This Innovation to Practice paper highlights one effort to meaningfully integrate mathematics and science through engineering in middle school classrooms. The STEM-ID engineering course sequence consists of three 18-week middle school engineering courses. Each of the 6th, 7th, and 8th grade courses integrate science and math with engineering design, enabling students to explore and practice foundational math and science skills in a low-risk, non-high-stakes-tested environment. This Innovation to Practice paper provides illustrative examples of STEM-integration through the STEM-ID curricula, focusing on four key areas: data analysis, measurement, experimental design, and force and motion concepts. Drawing on our project's implementation data, we highlight illustrative examples of STEM integration, in practice, and lessons learned by educators and researchers involved in the project.

Nearly a decade after the publication of the National Academy report *STEM Integration in K-12 Education* (2014), the landscape of integrated science, technology, engineering, and mathematics (STEM) education includes an array of approaches to connecting STEM disciplines (Moore et al. 2020; Moore and Smith 2014; Nadelson and Seifert 2017). At the same time, a coherent approach to STEM education remains somewhat elusive, with teachers often struggling to connect STEM disciplines. Traditional teaching of STEM subjects in isolation often fails to engage students or to reflect the interconnected nature of real-world challenges. The relevance of STEM subjects is heightened when STEM is taught in connected ways, especially in real-world contexts (NRC 2014a, 2014b), with successful efforts to increase STEM learning involving interdisciplinary approaches (English 2016; Gao et al. 2020), even when one subject remains dominant (Burghardt et al. 2015). Given the complexity of combining science, technology, engineering, and mathematics in authentic contexts, there is a clear need for descriptions of curricula that support STEM integration (Berland 2013; Bybee 2010; Moore and Smith 2014; Wan et al. 2023). This Innovation to Practice paper shares illustrative examples from one effort to realize the goals of STEM integration, the middle school STEM Innovation and Design (STEM-ID) courses. The Innovation to Practice paper is guided by the question: In what ways can problem-based, integrated STEM curricula increase middle school engineering students' engagement and provide opportunities for engineering teachers to integrate foundational science and mathematics?

The STEM-ID engineering course sequence consists of three 18-week courses (one each for the 6th, 7th, and 8th grades) designed to integrate science, math, and engineering content and skills through contextualized problem-based learning. The problem contexts are a carnival for 6th grade, aviation for 7th grade, and robotics for 8th grade. Each course is comprised of a series of challenges (Data Challenge, Systems Challenge, Visualization Challenge, and Design Challenge), the first three of which build different skills leading to the culminating Design Challenge. Each of the 6th, 7th, and 8th grade courses strategically integrates science and math with engineering design, enabling students to explore and practice engineering, math, and science skills in a low-risk, non-high-stakes-tested environment. These skills fall within four major categories: (1) Engineering Design, (2) Cross-Disciplinary Application of Math and Science Practices, (3) Foundational Math, and (4) Communication. The explicit inclusion of foundational math and science practices such as graphing, measuring, estimating, designing experiments and standardizing procedures, and collecting data within the context of engineering enhances the course experience for students by reinforcing content from their core math and science courses. The course sequence also introduces students to computer-aided drafting (CAD) and 3D printing as powerful tools for prototyping and testing solutions to authentic challenges. By 8th grade, students develop proficiency using professional CAD software (e.g., AutoCAD Inventor) to model and prototype original 3D designs, thus providing challenging, authentic engineering design experiences with advanced manufacturing technology that meet or exceed expectations set by engineering standards.

Curriculum developers drew from three sources in compiling the content and practices to be included in each course: the Next Generation Science Standards (NGSS Lead States 2013) for science, the Standards of Mathematical Practice (Illustrative Mathematics 2012) for math, and the Georgia state Engineering and Technology course standards for engineering. Such engineering course standards range from more general engineering and career-oriented content (e.g., "Identify engineering and technology and its impact on society") to more technical and high-level engineering practices including ("Use the EDP along with the systems model in the production of a prototype to a design problem").

Another key component of the STEM-ID curricula is that they are grounded in the strong tradition of problem-based learning (PBL; Barrows 1985; Collins et al. 1989; Kolodner et al. 2015). In PBL, students work collaboratively to solve a compelling and authentic problem and, in doing so, identify what additional knowledge and skills they will need to solve the problem. This PBL approach, coupled with core engineering ideas and practices as well as repeated opportunities to practice foundational math and science skills, offers a unique approach to STEM learning, that sets STEM-ID apart from more traditional middle school engineering and technology courses. Another unique aspect of STEM-ID is the cohesive, integrated nature of the semester long curriculum that follows a single learning arc with a uniting problem context, as compared to a more traditional approach to engineering instruction comprised of a sequence of modules or activities on various topics. Table 1 summarizes the activities and relevant standards included in each course. For readers who are interested in reviewing the full curriculum, targeted learning outcomes, research findings, and course materials for potential use in their own classroom contexts, the full curricula are available at https://sites.google.com/ceismc.org/stem-id-engineering.

Previous research on outcomes of the STEM-ID curricula demonstrated that enabling students to apply science and math through engineering design significantly benefited both academic achievement and STEM engagement. One study investigated the impact of the curriculum (Alemdar et al. 2018) found that students who participated in STEM-ID for two or more years achieved significantly higher scores on mathematics and science standardized tests than peers who did not take the course. This study also demonstrated a significant increase in cognitive and behavioral engagement in STEM and interest in science. The study suggests that the opportunity to practice science and mathematics knowledge and skills in an engaging engineering course can have a significant, positive impact on both achievement and engagement in STEM. In another study (Gale et al. 2018), case studies of students who participated in the course for multiple years documented increases in student self-efficacy for engineering and increased interest in pursuing engineering careers. Specifically, interview data gathered in that study indicated that students recognized connections between their course activities and potential engineering careers and that taking the STEM-ID courses increased students' confidence in pursuing such careers. Based on these promising findings, our current project, funded by a National Science Foundation (NSF) Discovery Research K-12 (DRK-12) grant, seeks to scale the STEM-ID curricula to reach a larger population of middle school students and to develop additional insights into the efficacy of the curricula as it is implemented across different school contexts.

1 | Math-Science Integration as a Critical Component of STEM-ID

Guided by the Innovation Implementation Framework (Century and Cassata 2016), our team identified the integration of mathematics and science as one of several critical components of the STEM-ID curricula. This meant that, as we collected implementation data, we paid special attention to the ways in which teachers facilitated and students engaged in activities integrating science and mathematics. To this end, we have accumulated a wealth of observation, interview, and survey data related to STEM integration in participating classrooms. Observers visited classrooms periodically during curriculum implementation to conduct observations using a semi-structured protocol developed by the project team. The protocol contains a general section for student actions and teacher actions recorded in 5-min increments during the class session as well as specific sections dedicated to each of the critical components of the curriculum. The Math/Science Integration section instructs observers to indicate math/science integration activities that students engaged in during the class session, noting specific concepts, vocabulary, and practices, including measurement, data analysis, experimental procedures, and any other math or science concepts. Teachers were interviewed at the end of each semester of curriculum implementation. In these interviews, they were asked specific questions about math/science integration, including whether and how they had observed their students making connections

TABLE 1 | STEM-ID overview.

Course	Description	Standards
6th Grade "Carnival Tycoon"	Students explore the engineering design process and entrepreneurial thinking in the context of a carnival. The course begins with students making a sales pitch for a new carnival food stand based on market research. Students then run experiments using a pneumatic catapult, and they must design a new carnival game board with appropriate odds of winning. Then, after skill development in engineering drawing, they re-design the catapult cradle to change the performance characteristics of their carnival game. Students incorporate math and science content, including data representation, probability, experimental procedures, profit calculations, drawing, and measurement.	• NGSS Practice 4. Analyzing and Interpreting Data. • NGSS Practice 6. Designing Solutions (for engineering). • NGSS Practice 8. Obtaining, Evaluating, and Communicating Information. • Standards for Mathematical Practice (SMP) 1: Make Sense of Problems (i.e., plan a solution pathway). • SMP4: Model with Mathematics (i.e., map relationships using diagrams, two-way tables, graphs). • SMP5: Use Appropriate Tools Strategically. • CCSS.Math.Content.6.NS.C.8: Solve real-world and mathematical problems by graphing points in all 4 quadrants of the coordinate plane. • CCSS.Math.Content.6.G.A.4: Represent three-dimensional figures using nets made up of rectangles and triangles, and use the nets to find the surface area of these figures.
7th Grade "Flight of Fancy"	Students pose as new airline companies and redesign airplanes to be more comfortable, profitable, and environmentally friendly. This is accomplished through a series of challenges, starting with a test flight of different Styrofoam gliders. Students examine interior layouts, learn 3D modeling in Iron CAD, and finally, re-design a plane using a balsa glider as a model. Students incorporate math and science content, including measurement, proper experimental procedure, data analysis, and profit calculations.	• NGSS Practice 4. Analyzing and Interpreting Data. • NGSS Practice 6. Designing Solutions (for engineering). • NGSS Practice 8. Obtaining, Evaluating, and Communicating Information. • Standards for Mathematical Practice (SMP) 1: Make Sense of Problems (i.e., plan a solution pathway). • SMP4: Model with Mathematics (i.e., map relationships using diagrams, two-way tables, graphs). • SMP5: Use Appropriate Tools Strategically. • CCSS.Math.Content.7.G.A.1: Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale. • CCSS.Math.Content.7.G.A.2: Draw (freehand, with ruler and protractor, and with technology) geometric shapes with given conditions.
8th Grade "Robot Rescue"	The course is intended to further build student understanding of the engineering design process and entrepreneurship. The course begins with a short design challenge, requiring the students to design and 3D print a cell-phone holder. Students then conduct experiments using a bio-inspired walking robot. The course ends with an open-ended challenge to design a rescue robot capable of navigating variable terrain. During these challenges, students use robotics, 3D CAD modeling software, and 3D printing technologies. In addition, students incorporate math and science content, including modeling, data analysis, scientific procedure, force and motion concepts (e.g., velocity, speed, friction), and systems thinking.	• NGSS Practice 4. Analyzing and Interpreting Data. • NGSS Practice 6. Designing Solutions (for engineering). • NGSS Practice 8. Obtaining, Evaluating, and Communicating Information. • NGSS Disciplinary Core Idea PS2.A: Forces and Motion. • Standards for Mathematical Practice (SMP) 1: Make Sense of Problems (i.e., plan a solution pathway) • SMP4: Model with Mathematics (i.e., map relationships using diagrams, two-way tables, graphs). • SMP5: Use Appropriate Tools Strategically. • CCSS.Math.Content.8.F.B.4: Construct a function to model a linear relationship between two quantities. Determine the rate of change and initial value of the function from a description of a relationship or from two (x, y) values, including reading these from a table or from a graph.

between what they had learned in their math and science classes and what they are doing in STEM-ID. Implementation surveys serve to record teachers' progress through curriculum components, presenting them with a checklist of curriculum elements they can use to indicate which parts they did and did not implement. Triangulating across these data sources allowed researchers to draw a clear picture of the extent to and manner in which teachers facilitated science and math integration within the context of their STEM-ID implementations.

STEM-ID students regularly practice foundational mathematics such as measurement, computation, estimation, graphing, and mathematical reasoning alongside their grade-level math and science courses. STEM-ID also foregrounds specific science practices including developing and refining testing procedures, conducting investigations, using data collection tools, and collecting and analyzing data. As students develop design solutions, they set up and run tests, record test results, identify variables leading to inconsistent results, refine testing procedures, re-run tests, and graph data to demonstrate data convergence as procedures become standardized. Although STEM-ID courses do not explicitly teach or assess grade-level science standards, across the three courses students have opportunities to deepen their conceptual understanding of key science concepts related to the contextualized themes for each of the grade-level courses. The STEM-ID courses utilize an interdisciplinary learning arc that includes concepts, practices, and applications. The concepts include the core ideas from science, engineering, and math. The students use these ideas to engage in practices such as defining problems, analyzing data, evaluating solutions, and so forth, generally following the engineering design process, working collaboratively towards the solution of a design problem bound within the authentic context of their grade level (i.e., carnival, aviation, or robotics).

Below we highlight illustrative examples of STEM integration drawn from teacher interviews and classroom observations conducted as part of our project's implementation research, which is one strand of a larger research program. The illustrative examples shared in this paper are drawn from data gathered during the second year of this scaling effort (2023–24), in which the curricula were implemented in seven middle schools in a large metropolitan school district in the southeastern United States. Researchers observed implementation of all three grade level curricula for a period of approximately 2 weeks in five teachers' classrooms, yielding a total of 125 classroom observations. During observations, researchers completed a semi-structured protocol including both checklist items and field notes to describe how the various critical components of STEM-ID were being implemented, including the math/science integration component. The protocol also asked observers to provide ratings of overall student engagement and field notes describing any patterns in engagement observed. Specifically, researchers were asked to rate the overall student engagement level over the course of observed class sessions as low (< 20% students engaged), medium (20%–80% students engaged), or high (> 80% students engaged). Additionally, researchers conducted 30–45-min interviews with all seven teachers participating in the project at the end of each semester. Interviews used a semi-structured protocol that asked teachers to reflect on their implementation of each grade level curricula, how they facilitated the engineering design process, their approach to math-science integration, and contextual factors influencing implementation.

Although math-science integration occurs in various ways across the curricula, we have chosen to highlight illustrative examples in four key areas where the integration of math and science is most salient within the curricula: Measurement, Data Analysis, Experimental Design, and Force and Motion Concepts. Following this discussion of illustrative examples, we conclude with a brief discussion of perspectives on STEM integration expressed by teachers implementing the curricula and findings pertaining to student engagement.

2 | Measurement

In STEM-ID, students learn the importance of precise measurement for engineering design. Challenges ask students to conduct measurements for a variety of purposes using a variety of measurement tools. In sixth grade, students measure the landing distance of projectiles launched using a pneumatic catapult. In seventh grade, students measure the flight distance when testing gliders and use calipers to make precise measurements for CAD designs of new glider wings. In eighth grade, measurement activities include taking accurate measurements for use with CAD software in the design challenges and measuring distance and time to determine the velocity of robots in the robot rescue investigation challenges.

Given the prevalence of measurement within STEM-ID, it is perhaps not surprising that when we ask teachers to describe challenges related to students' mathematics and science skills, measurement is, by far, the most cited. Several teachers reported that, given learning gaps precipitated by the COVID-19 pandemic, students increasingly need to review foundational measurement skills (e.g., how to use a ruler, converting inches to feet) and teachers often provided additional scaffolding for measurement activities within the curricula. Indeed, in over 80% of observed class sessions where measurement activities occurred, teachers provided additional review activities or scaffolding to support students' application of measurement skills. For example, in anticipation of student challenges with measurements for their CAD designs in the Robot Rescue Design Challenge, two teachers provided additional instructions to help students include accurate measurements for the axel onto which the robot feet they design would need to fit. Figure 1 shows a slide projected by one teacher, providing the axel measurements, with the additional "tip" that students should start with a rectangular prism (box) that is 30 mm × 5 mm.

Similarly, another teacher provided hand-drawn diagrams (Figure 2) showing the axel dimensions along with notes on additional dimensions students should keep in mind when designing their robot feet (e.g., interior and exterior leg lengths, distance between axels, length of testing track).

Thus, the curricula not only imbed opportunities for students to apply measurement skills but also provides teachers with ample opportunity to address any gaps in students' understanding of measurement.

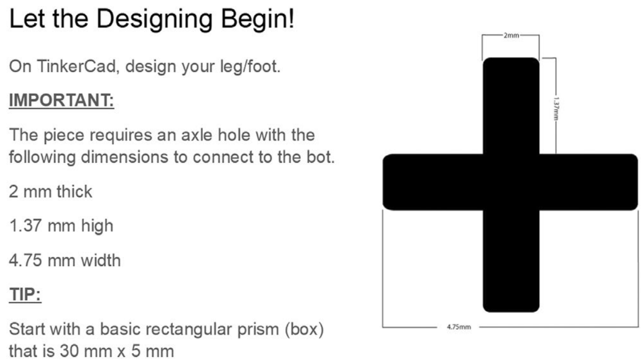

FIGURE 1 | Slide presented during 8th grade robot rescue design challenge.

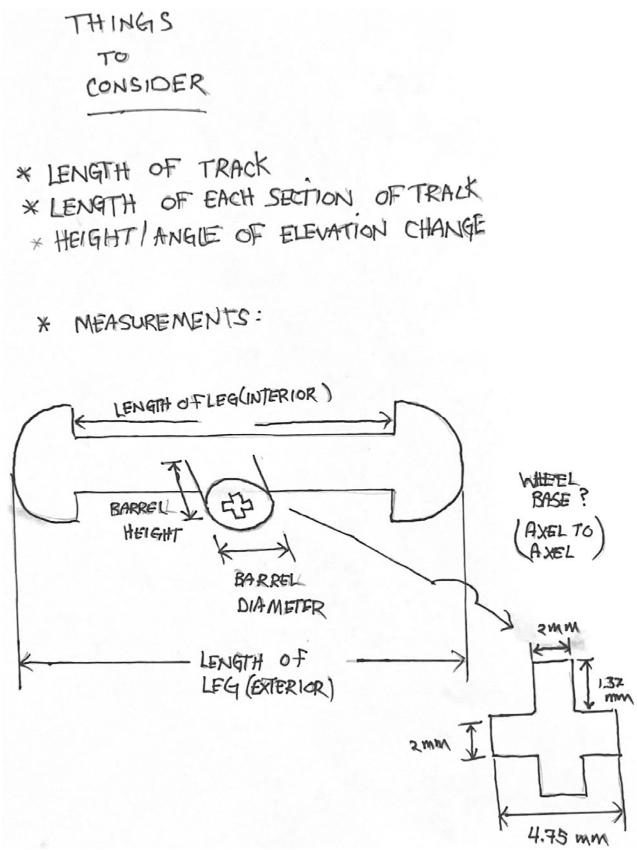

FIGURE 2 | Teacher drawing with measurement notes for robot rescue challenge.

3 | Analyzing Data

At each grade level, students have multiple opportunities to collect, analyze and interpret data. For example, the sixth grade Carnival Tycoon course begins with a "What is Data?" activity in which students collect data from their classmates, discuss different types of data (quantitative and qualitative), and explore data as a tool for decision making as they review a Shark Tank video and discuss the types of data needed to help the Sharks make sound investment decisions.

In addition to confirming that teachers engaged students in collecting and analyzing data, we noted several instances in which teachers used data analysis activities to review foundational mathematics concepts. For example, in one seventh grade class session where students were collecting test data on their gliders, one teacher engaged students in a discussion of measures of central tendency, asking "Why do we use the mean rather than the median or the mode when we are testing the gliders? What does the mean tell us?" In another example, a teacher adjusted course while having students plot their glider data upon realizing that students were not familiar with histograms stating, "I have to digress, because I didn't know you didn't know what histograms were. I thought math teachers would have gone over what a histogram is. So, we'll do some math teaching now, not a problem." The teacher then supplemented STEM-ID activities with an instructional video on constructing histograms. When this same lesson was observed the next semester, the teacher anticipated that students may need to review histograms and used the video as an introductory activity prior to having students plot their own data. Thus, our implementation data indicate that fully engaging students in data analysis activities included in the curricula may require engineering teachers to review additional foundational mathematics concepts.

4 | Experimental Design and Control of Variables

Although students gain experience with experimental design throughout the curricula, the seventh grade "Flight of Fancy" Data Challenge explicitly builds student understanding of the importance of developing consistent procedures. In this challenge, students work in groups to test the performance of foam gliders with four different wing shapes, collecting 10 flight trials with each wing type. In this first round of testing, students are not given any guidance on their procedure—they are merely told that they must stand at the start line and when the glider lands, measure the distance traveled. Predictably, in this first round of testing, results within and across groups are quite "messy." In a class discussion, students then review histograms for the first round of testing and identify variables (besides wing shape) that may affect the flight distance of the gliders. Variables students often identify include: the unit of measure used, how hard the glider was thrown, the angle at which the glider was thrown, the height of the thrower, how distance was measured (to the front or back of glider), who threw the glider each time. Students then develop a standardized class procedure to control as many variables as possible in order to figure out which wing shape performed best (e.g., flew the furthest distance). Following a second round of testing using the standardized procedure, students compare results with the previous test to demonstrate how, although some variability cannot be eliminated, controlling variables leads to more trustworthy data with a narrower spread across groups.

Observation data indicate that activities in which students collect flight data for various wings and refine and standardize procedures represent a high point for student engagement within the curricula. Observers rated students as highly engaged in 90% of these class sessions. Analysis of field notes collected over four implementations of the 7th grade course indicates that, across teachers and schools, students engaged excitedly in data-driven discussions of the potential advantages and disadvantages of the various wing designs and often demonstrated a high level of investment in collaboratively developing procedures for throwing the gliders and measuring glider flight distance that would result in more consistent findings.

5 | Force and Motion Concepts

In the eighth grade "Robot Rescue" Investigation Challenge, students conduct a series of investigations to explore the physical science concepts of slope, friction, and velocity as they work with a robot navigating a variety of surfaces under different operation conditions. In one surface investigation, students collect data on how the robot moves across surfaces with varying levels of friction. Students then repeat the investigation after altering the friction of the robot feet by adding various materials (e.g., felt, latex, sandpaper) to further investigate how variations in friction affect robot performance. Figure 3 shows the data sheet students use for this investigation. In another set of investigations, students apply the formula for velocity, measuring the time and distance robots travel to determine velocity under different conditions.

Having identified apparent differences in the slope according to motor speed, students then use the formula for slope to calculate the slope for each of their rotation lines. Students then use their slope calculations to reason about the robot's performance, determining at which speed program the robot moved fastest, which demonstrated the most slippage and why. Notably, depending on whether students are taking the course in their first or second semester of eighth grade, this work with the concepts of slope, velocity and friction may be either a preview or a review of content covered in their eighth grade mathematics and physical science courses.

Observations also indicated instances where the curricula served as a springboard for teachers to draw connections to relevant science concepts not explicitly included in the curricula. For example, one teacher discusses the importance of science integration during implementation of the 7th grade course, sharing how he introduced students to Bernoulli's principle to help explain how an aircraft achieves lift because of the shape of its wings:

> The most important thing, is really connecting to the design process, but also the science and engineering concepts. It's not just building a kite. It's understanding the science of how a kite achieves flight. It's like we're understanding...we're going to learn about the parts of the plane and Bernoulli's principle, so they start to understand the science behind 'oh, this is how a plane actually stays in the air, this is how lift works and how the shape of the wings might be part of that'. So, it's about putting the engineering and the science together and applying it to an engineering situation and using the engineering design process.

We noted that such connections to science concepts were often made by teachers with previous science teaching experience. Based on these findings, our research team is continuing to investigate the implications of teacher background and the pedagogical content knowledge (PCK) teachers bring to curriculum implementation (PCK) (Gale et al. 2025).

6 | Teacher Perspectives on Math and Science Integration With STEM-ID

Teachers extolled the benefits of STEM integration in professional learning sessions and individual interviews. All seven teachers interviewed highlighted the integration of mathematics and science as a clear benefit of the curricula, often noting a desire to further develop their own understanding of individual STEM disciplines to enhance their ability to integrate math and science in their engineering classrooms. For example, when asked about math-science integration, one teacher stated "I love it. I like to do it as much as possible. I wish I had a better background in physical science, like the physics aspect of it, especially for my eighth graders, but that's something I'm working on developing, like my mechanical and electrical engineering knowledge." Teachers also appreciated opportunities to draw connections between STEM-ID and concepts students were learning in their math and science classes. For instance, in describing her experience working with 8th grade students to assemble robots for the 8th grade Robot Rescue Systems challenge, one teacher noted "when we were talking about the electrical system, they had just done electricity in science... So when we're talking about the electrical system and the circuit and some of the components, they were like, 'oh, we just talked about this'. So, they knew about that."

Teachers also frequently discussed the parallels between the engineering design process and the scientific method. In a lively discussion at the project's summer Professional Learning Institute, one teacher shared their goal to teach students to "think like a scientist and an engineer," adding that former students have visited after taking his STEM-ID classes discussing how "their thinking has changed." Indeed, during implementation, this teacher was often observed drawing analogies between the scientific method and the engineering design process.

Teachers also discussed how the curricula's integration of mathematics addressed the need to strengthen foundational skills after the COVID-19 pandemic. For instance, during the demonstration of the 8th grade curriculum at the Summer Professional Learning Institute, one teacher expressed that he appreciated the inclusion of plotting X/Y coordinates, noting that "because of COVID, whatever extra math practice they can get is so helpful." In subsequent interviews conducted following implementation in the Fall of 2023, all teachers affirmed the clear need for opportunities to review and practice foundational mathematics skills, often citing students' challenges with measurement as an area of particular concern.

7 | Student Engagement

Teachers often discussed how integrating math and science through engineering enhanced student engagement. For example, one teacher who came to teaching engineering from

Surface Investigation Worksheet

Group Number: ______ Group Members: ______

Date: ______

What material is on your foot? Plastic ☐ Felt ☐ Latex ☐ Sandpaper ☐

Surface Used for test.	Measurement	Trial #1	Trial #2	Trial #3	Trial #4	Trials #5
Carpet	Time in seconds					
	Distance in cm.					
Rubber Mat	Time in seconds					
	Distance in cm.					
Striped Board	Time in seconds					
	Distance in cm.					

Carpet Average Time in seconds ______

Show Work Here

Carpet Average Distance in cm. ______

Show Work Here

Rubber Mat Average Time in seconds ______

Show Work Here

Rubber Mat Average Distance in cm. ______

Show Work Here

Striped Board Average Time in seconds ______

Show Work Here

Striped Board Average Distance in cm. ______

Show Work Here

FIGURE 3 | Robot rescue surface investigation student sheet.

a background teaching language arts drew connections between the engagement she saw in her classroom and her own experience as a student:

> It was good to see the kids so incredibly engaged…I don't know if I would see the same kind of engagement if I were teaching just math or just science. I don't know. I've never been in that room before. But, to me as a kid, I was not super crazy about math and science. I was a language arts, social studies girly, but if I were in a class where I saw it applied like this and we had meaningful discussions about it, it would've meant a lot more to me.

Indeed, such teacher reflections were consistent with ratings of engagement gathered across 125 class sessions. As indicated in Figure 4, across grade levels, engagement was rated as high most frequently and ratings of low engagement were rare.

Field notes describing engagement patterns indicated that engagement was particularly high as students designed prototypes using CAD software and tested prototypes during design challenges. Engagement was somewhat lower during activities where students conducted research to deepen understanding of engineering problems or developed presentations to share their designs.

8 | Future Directions

A number of future directions for curriculum development, teacher professional learning, and research have emerged from our recent experience observing and interviewing teachers about their experience with the STEM-ID curricula. As they are frequently the only engineering teachers in their school

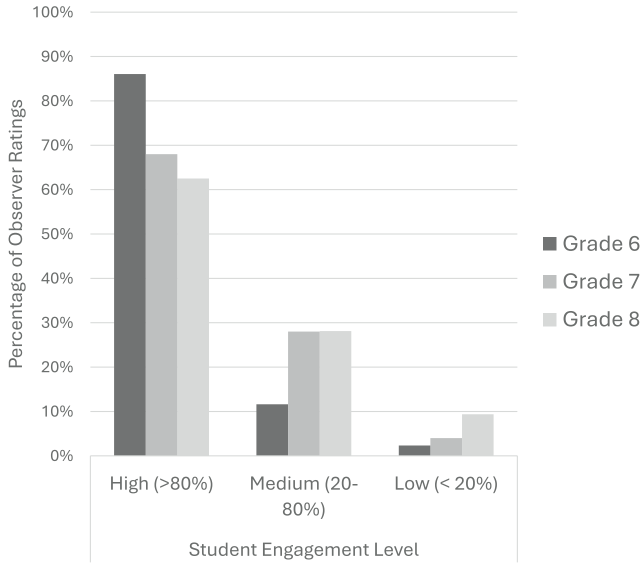

FIGURE 4 | Student engagement ratings by grade level.

building, we have found that teachers benefit greatly from participating in a PLC of teachers working with the same curriculum across schools. Ongoing virtual check-ins with their peer teachers in the study as well as research staff provide critical opportunities to reflect on instruction, troubleshoot issues as they arise, and share resources and best practices. Through these PLC discussions, the project has been able to identify certain topics, such as robotics and CAD software, as priorities for ongoing teacher professional learning. The curricula materials provide clear guidance and resources for implementation, while allowing latitude for teachers to supplement, scaffold, and otherwise adapt STEM-ID to meet the particular needs of their students. To understand how the curricula are adapted in different settings, we have begun to examine how various contextual factors influence implementation (Gale et al. 2024) and the types of adaptations engineering teachers tend to make (Gale et al. 2025). Drawing connections between teacher decision-making about adaptations during implementation and outcomes for the overall efficacy of the curriculum as well as teacher and student outcomes represents a next step in this line of research. Similarly, as we have found significant variations in the time and resources engineering teachers have available to devote to enacting a semester-long curriculum, we have begun working with teachers who have shorter timeframes for implementation to streamline challenges and prioritize certain key activities within each grade level course. Whether this abbreviated version of the course sequence produces similar outcomes for students remains to be seen. Finally, while our work focuses on understanding full curriculum implementation in engineering classrooms, future work may explore whether and how certain activities within the larger course sequence could be adapted by mathematics or science teachers interested in incorporating problem-based engineering or advanced manufacturing technology (CAD, 3D printing, and robotics).

9 | Conclusion

Although the examples shared here occurred in the context of the engineering classrooms in which we work and cannot necessarily be generalized broadly, we do see possibilities for inspiring STEM integration efforts in a variety of settings, including core math and science classrooms. Engineering teachers are welcome to utilize these publicly available curricula in their classrooms, either partly or in full, and science and math teachers could implement relevant activities to provide students with practice on specific content and skills. Over the decade spanning our original design research and our more recent scaling efforts, we have seen, time and time again, the benefits of giving students opportunities to practice and apply STEM knowledge and skills through the engineering design process. Applied engineering problems provide a motivating and low-risk context in which students are invited to apply math and science knowledge and skills to solve the engineering problems set out for them in the STEM-ID curricula.

In addition to heightened student engagement, we've found that STEM integration through activities like those shared here has clear potential for strengthening foundational math and science, a particularly acute need considering learning gaps.

Our project also highlights the potential for teachers with a range of backgrounds to meaningfully engage students in STEM integration through engineering design. Indeed, the activities from the curricula shared here have been implemented by veteran and novice engineering teachers, teachers coming to the engineering classroom from teaching various other disciplines, and teachers with a background in industry. At the same time, our observation that teachers draw on their unique backgrounds as they make connections to STEM content highlights the value of cross-disciplinary expertise, suggesting the potential for collaboration among integrated teams interested in enacting STEM-integrated engineering activities like those in the STEM-ID courses.

STEM-ID represents one promising approach to integrating science and mathematics through engineering at the middle school level. As students complete STEM-ID challenges, they find that, just as engineers employ mathematics and science, successfully completing engineering design challenges requires applying and building upon the foundational mathematics and science understandings they bring to the engineering classroom. It is our hope that the illustrative examples shared here may contribute to ongoing discussions of STEM integration strategies and inform the challenging work of integrating STEM disciplines in practice.

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