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Bridging Disciplinary Boundaries: Math and Science Integration in K-12 Engineering Education (Evaluation)

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Engineering is a highly interdisciplinary endeavor, drawing heavily on math and science in its applied and systematic approach to solving problems. As engineering content and skills are increasingly integrated into K-12 spaces, the necessity of utilizing math and science in the practice of engineering both presents an opportunity and highlights gaps in learning and motivation. Hands-on, engaging engineering problems that demand the use of foundational math and science for their solutions can serve as a more motivating context than stand-alone worksheets or word problems, offering students an inviting, relevant, and even enjoyable setting in which to further hone these basic skills. However, courses such as engineering are typically taught as electives or "connections" courses, and as such can be taken less seriously by students as compared to core courses; students often balk at the idea of being expected to do "real work" in these courses, especially work that they perceive as being outside the scope of the elective course. Moreover, students' misconceptions or gaps in knowledge in critical math or science skills can present roadblocks to their progression through engineering problems that require these skills. Given these potentially conflicting roles of math and science application in the K-12 engineering space, math-science integration within the context of an engineering curriculum implementation presents a fruitful area for investigation.

In this paper, we present results from a mixed-methods study examining student and teacher experiences and outcomes within a middle school engineering curriculum. Specifically, we focus on how teachers from various subject matter backgrounds a) approached science and math integration as they implemented the engineering curriculum and b) experienced their students' skills within and motivation around these topics as they progressed through the curriculum. From the student perspective, we examine students' levels of math and science anxiety and academic self-efficacy prior to and after their experience with the course. Results suggest that teachers are highly motivated to provide supplemental math and science instruction as they implement the engineering curriculum, particularly when they observe students struggling with skills that are critical to successful enactment of curriculum activities, (e.g., measurement). Teachers also see the value of engineering problems as a motivator for students who might otherwise have little interest in practicing their math and science skills. Our previous study of this curriculum found that students' math and science anxiety slightly decreased**,** while participation in the course was associated with greater cognitive and behavioral engagement in STEM and a significant increase in science interest**.** These results suggest that sustained exposure to engineering instruction can strengthen both students' academic performance and their motivation toward STEM learning. Building on these findings, the present study further examines changes in math and science anxiety, science interest, and self-efficacy before and after students' experience with the course.

Introduction

Engineering has become an increasingly important component of K-12 STEM education, reflecting broader efforts to integrate math and science in meaningful and applied ways [1], [2]. Engineering curricula naturally draw upon core math and science concepts and offer a promising context for supporting students' development of foundational math and science skills through authentic problem-solving.

Despite the potential benefits to math and science education offered by engineering curricula, many students continue to experience challenges, which have been further exacerbated by the COVID-19 pandemic. Recent research indicate that pandemic-related school closures had a significant negative impact on student achievement, particularly in math and science, and many students have not yet fully recovered to pre-COVID academic performance levels [3]. The Northwest Evaluation Association (NWEA) conducted a longitudinal study in the United States to examine student achievement post-pandemic for math and science in grades 3rd through 8th by comparing standardized test scores between pre-pandemic in 2019 and post-pandemic in 2024. Findings showed that for science, while students in elementary school have rebounded to near pre-pandemic levels, middle school students, especially in seventh and eighth grades, continue to fall behind their pre-COVID peers [4]. For math, while test scores are showing improvement every year across all grade levels, all grades are still scoring below the pre-pandemic levels [5].

Integrating engineering into math and science instruction can positively influence students' conceptual understanding, engagement, and learning outcomes [6], [7]. Engineering design-based learning environments also encourage students to engage in inquiry-based, open-ended problem-solving that requires the application of math and science knowledge and practices. Through activities such as measurement, data analysis, and testing design solutions, students naturally engage in higher-order thinking practices such as logical reasoning, algorithmic thinking, and iterative problem-solving [8] – [10].

As engineering instruction becomes more prevalent in pre-college education, teachers from a wide range of disciplinary backgrounds, including math and science, are transitioning into engineering classrooms. Middle school is a critical developmental period in which students' attitudes toward learning are closely linked to their future interest in post-secondary education and career paths [6]. However, student engagement in elective courses, the context in which K-12 engineering is often taught, can be challenging; Fredericks et al. [11] suggest that some students show disengagement in elective or connections courses when these courses mirror traditional core content courses, as they seek greater autonomy with more flexibility in exploring topics they like in elective or connections courses. Therefore, to shape students' engagement and academic skills, teachers should understand the coherence of integrated teaching approaches and learning approaches [9] and leverage engineering courses as a motivating context for learning.

A middle-school STEM-integrated curricula, STEM Innovation & Design (STEM-ID), is a one-semester, problem-based engineering curriculum for grades 6-8. The course is offered as a connections course (i.e., elective). Prior research exploring the effects of STEM-ID has demonstrated that students frequently recognize and articulate connections between engineering activities with math and science and described engineering tasks as opportunities to practice and reinforce math and science skills [12]. The STEM-ID curriculum was associated with improvements in standardized math and science scores over time [13]. Building on this prior work, the present mixed-methods study examines teacher and student experiences with math and science integration in STEM-ID. Specifically, we investigate how teachers approach math and science integration during curricula implementation and how they perceive students' skills and motivation. Changes in students' math and science anxiety and academic self-efficacy over the course of their experience with the STEM-ID curricula are also explored. The study is guided by the following questions:

1. How did teachers approach math/science integration during their implementation of STEM-ID?
2. What are teachers' perceptions of their students' skill and motivation levels for math and science during their implementation of STEM-ID?
3. To what extent does participation in STEM-ID impact students' standing on science and math anxiety, engagement, and interest?

Method

Participants

Participants include both teachers and students participating in curriculum implementation within a three-year period spanning the 2022-23, 2023-24, and 2024-25 school years. Teacher and student samples are described below.

Teachers

Participating teachers (n=16) are all from two school districts in the metro area of a large Southeastern city. Teachers represent three cohorts recruited to participate in the program each year, with support from district and school leaders encouraging adoption of the curriculum. Prior to implementing the curriculum, each cohort participated in the program's summer professional learning institute, a 5-day sequence of experiential learning workshops in which teachers worked through the curriculum, gained technical knowledge and experience with equipment and materials used in the curriculum, and engaged in collaborative planning to design implementation plans for their classrooms. Demographics and teaching background data on the teacher participants are provided in Table 1 below.

Table 1

Teacher participants: Demographics and teaching background

Pseudonym	Cohort	Included in Observ. Data?	Included in Interv. Data?	Included in Survey Data?	Total Years Teaching	Years teaching engineering	Years teaching STEM-ID	Professional and Educational Background	Demographics
Sally	1	Y	Y	Y	18	3	3	Former Math teacher B.A. and M.A.T. in Education	White Female
Neil	1	Y	Y	N	30	9	6	Former Science teacher B.A. and M.A.T. in Education	White Male
Kathryn	1	N	Y	N	8	0	5	Computer Science Teacher B.A. in Education	White Female
Stephanie	1	Y	Y	N	18	1	1	Former Math teacher B.A. in Mathematics, M.A.T. in Education	Black Female
Jeanette	1	Y	Y	Y	31	5	5	Former Science teacher B.A. in Biology, M.A.T. in Education	Black Female
Pete	1	N	Y	N	21	4	3	Former Science teacher B.A., M.A.T., and PhD in Education	White Male
John	2	Y	Y	Y	2	2	2	Industry Background: 20 years as Computer Science Engineer B.S. in Computer Science	White Male
Shannon	2	Y	Y	Y	8	2	2	Former Science teacher B.S. in Communications, M.A.T. in Middle Grades Math and Science	White Female
Ellen	2	Y	Y	Y	10	2	2	Former Language Arts teacher BASc in Secondary Education and Teaching	Hispanic Female
Alan	2	Y	Y	N	10	1	1	Former Science teacher B.A. in Education	White Male

Jim	2	Y	Y	Y	23	23	2	Career engineering teacher B.S., M.A. in Social Sciences	White Male
Scott	3	Y	Y	N	22	12	1	B.S. in Environmental Health, MBA, Co-teaches with Michael	White Male
Michael	3	Y	Y	N	13	2	1	Previously taught Social Studies. B.A. in History, M.A.T in Social Studies Education	White Male
Frank	3	N	Y	N	5	1	1	Former Math, ELA, Social Studies teacher. B.A. in English, MA in Human Communication and Social Influence.	Mixed Race, Male
Sheila	3	N	Y	N	18	8	1	B.S. in Engineering, M.A.T in Education; Previous career as Systems Engineer	Black Female
Joan	3	N	Y	N	20	11	1	B.S. in Engineering, M.A.T in Education	Black Female

Students

Student participants were 7^{th} and 8^{th} grade engineering students enrolled in one of six schools where survey data were collected during the 2024-25 school year. The survey sample includes a total of 305 students, consisting of 60% male and 40% female participants. In terms of race and ethnicity, 28% of students identified as Asian, 27% as African American, 20% as White, and 18% as Hispanic. The remaining students either identified as Other (5%) or did not report their race/ethnicity. Parent/guardian permission and student assent were obtained for all survey participants.

Instruments & Data Collection

Teacher Interviews

Semi-structured interviews were conducted with each teacher implementing the curriculum during the 2022-23, 2023-24, and 2024-25 school years. Four researchers conducted a total of 43 individual interviews. Interviews were scheduled at the end of each semester, as teachers were completing implementation. Whenever possible, interviews were conducted in person in teachers' classrooms. Otherwise, interviews were conducted online using teleconferencing software (e.g. Zoom). All teacher interview sessions were audio-recorded and transcribed for analysis.

Interviews were guided by a semi-structured protocol designed to elicit teachers' reflections on their experience implementing the critical components of the curriculum, including the integration of mathematics and science. The protocol contained a set of core questions that remained the same across academic years, with additional questions added based on emerging research findings and observed patterns that the research team wished to explore in more depth. Interview questions related to math-science integration include:

- What are your thoughts about integrating mathematics and science in engineering classrooms?
- Have you noticed whether students make connections between what they have learned in their math and science classes and what they are doing in STEM-ID? If so, can you give any examples?
- Tell me about your approach to incorporating math and science (content and skills). Have you been able to integrate math and science as you've implemented STEM-ID?
    - Are there math/science concepts within STEM-ID that you were not able to cover?
- Did you introduce additional connections to math/science? If so – can you give any examples?

Classroom Observations

Classroom observations were conducted in a sample of teachers' classrooms each semester of curriculum implementation during the 2022-23, 2024-25 the 2022- 23 school years. The number and selection of classrooms for observations were determined based on the availability of research personnel and teachers' stage of implementation, prioritizing observations in classroom where teachers had at least one previous semester of experience implementing the curriculum. Observations were scheduled such that one researcher observed implementation of culminating design challenges for each grade level curricula, spending approximately two weeks in a single teachers' classroom. Over the course of the three year implementation period, five members of the research team observed a total of 240 class sessions across 11 teachers' classrooms. Observation data were recorded using a semi-structured protocol, which included both checklist items for researchers to indicate whether particular foundational math and science within the curriculum was observed as well as space devoted to field notes.

Student Surveys

All participating students were given a survey at the beginning and end of each semester in which they were enrolled in the STEM-ID course. Survey data utilized for this study is from surveys administered during teachers' 2nd or 3rd implementation years of the STEM-ID curriculum; often, teachers' first year of STEM-ID implementation is incomplete and as such is not expected to yield significant student impact.

This survey utilized a pre-post design, such that the same items were presented in both surveys to assess changes in the measured constructs over the course of the semester. The survey was administered during a single class period, took students approximately 30 minutes to complete, and utilized a paper and pencil format. The survey consisted of 56 closed-ended items and a single, open-ended item on the post-survey only. Survey constructs, number of items, and sources are provided in Table 2. All of these items were tested in previous research using the STEM-ID curriculum [13]. The instrument consists of Likert-type self-report items in which students are asked to describe their level of agreement. The response options range from Strongly Disagree‖ (=1) to Strongly Agree (=4). For the purpose of this paper, only the constructs presented in the table below are analyzed, each of which shows very good reliability based on Cronbach's alpha (> 0.80) [14].

Table 2. Student Survey Constructs.

Construct	Number of Items	Cronbach's alpha	Source(s)
Academic Self-efficacy	10	0.88	Science Motivation Questionnaire [15]; Is Science ME (ISME) [16]
Math & Science Anxiety	11	0.90	MAS-R [17]; Science Motivation Questionnaire [15]

Bandura [18] defines self-efficacy as an individual's judgment of their capability to successfully perform tasks within a specific domain. In this study, self-efficacy was operationalized as students' perceptions of their ability to understand challenging concepts in science, mathematics, and technology courses. Survey items were adapted from the *Science Motivation Questionnaire* [15]. An example item is: "I am confident I will do well on science tests."

Anxiety consists of two related components: nervousness and worry. Nervousness refers to the uneasy or uncomfortable feelings students may experience when thinking about their schoolwork, assignments, or examinations. Worry reflects students' concerns about their ability to perform well in these academic tasks. In this study, anxiety was measured through survey items related to both science and mathematics. Although prior research conceptualizes anxiety as encompassing both negative and positive emotional responses to mathematics and science, such as concern over poor exam performance (negative) or interest in the subject matter (positive) [19], [20], the present study focuses exclusively on the negative aspects of anxiety. Survey items were adapted from the *Science Motivation Questionnaire* [15] and the *Mathematics Anxiety Scale–Revised* [17]. Sample items include "I worry about my ability to solve math problems" and "Science makes me feel confused."

Data Analysis

Qualitative Data: Interview and observation data were analyzed using a process of sequential qualitative analysis recommended by Miles, Huberman, and Saldaña [21]. Codes were organized to capture recurring ideas and salient perspectives related to participants' experiences. Specifically, coding focused on identifying instances within the interview data and observation field notes that illustrated teacher experiences with and perspectives on integrating mathematics and science in their engineering classrooms as they implemented the curriculum. Observation checklist data were synthesized to describe the frequency of math-science integration overall, and across particular math and science concepts/practices.

Quantitative Data: Survey data were analyzed using a pre–post paired *t*-test to examine changes in students' responses over time. This approach was selected to account for the repeated-measures design, in which the same students completed surveys before and after program participation. Paired *t*-tests were conducted to compare mean pre- and post-scores for each construct measured in the survey. Statistical significance was evaluated using an alpha level of .05, and effect sizes were calculated to estimate the magnitude of observed changes.

Results

RQ1. How did teachers approach math/science integration during their implementation of STEM-ID?

Interview and observation data indicate that mathematics and science integration was a consistent feature of curriculum implementation across participating classrooms, providing insight into how teachers approached mathematics and science integration as specified within the curriculum, as well as instances in which teachers extended beyond curricular guidance to introduce additional disciplinary connections.

As expected, implementation of math and science integration mirrored overall curriculum enactment patterns, with teachers who completed more of the curriculum also tending to implement math and science–related activities more fully. Across classrooms, teachers most frequently integrated mathematics through review and remediation of foundational skills that students needed in order to engage successfully in engineering tasks. Measurement was the most commonly addressed concept, given its central role across grade-level curricula.
Teachers described engaging in explicit modeling, scaffolding, and differentiated instruction to support students' development of measurement and unit conversion skills. Ellen described a

multi-layered approach that combined whole-class modeling with targeted small-group instruction:

> *"So I had to model it for them… giving them a worksheet that had, on one side, conventional measurements and on the other side metric measurements. A big part of it was me modeling how to do conversions… Then I pulled them for small groups to show them, and the kids that didn't get it, I gave them a quiz. Based on those results, I either brought them to my small group or released them to do a bingo activity."* (Ellen)

Other teachers described similar instructional moves, often emphasizing the need to slow down engineering activities to ensure students had sufficient mathematical grounding. Sally explained, *"When we do a skill like finding the mean or probability, I'll go over the skill before I have them calculate it themselves,"* highlighting how disciplinary instruction was embedded directly within engineering tasks rather than taught in isolation.

In addition to measurement, teachers frequently integrated mathematics through data analysis and visualization activities. Observations confirmed that teachers engaged students in collecting, analyzing, and interpreting test data as directed by the curriculum, while also using these moments to reinforce foundational concepts. For example, during a seventh-grade lesson focused on glider testing, Sally prompted students to consider measures of central tendency, asking why the mean was more appropriate than the median or mode for comparing results. In another classroom, Jeanette paused instruction upon realizing that students were unfamiliar with histograms,*"I have to digress, because I didn't know you didn't know what histograms were. I thought math teachers would have gone over that. So, we're going to do some math teaching now — not a problem."*

When the same lesson was observed the following semester, the teacher anticipated this gap and proactively introduced histogram construction before students analyzed their own data, illustrating how teachers adapted their instructional strategies over time.

Science integration tended to be less explicit than mathematics integration but remained well aligned with curriculum activities. Teachers most often drew on science concepts as students refined testing procedures or interpreted prototype performance. In eighth-grade design challenges, teachers and students discussed force and motion concepts such as friction, torque, and velocity as they iteratively tested robot components. In some cases, teachers extended beyond curricular content by introducing additional science explanations, particularly when they had prior science teaching experience. For instance, during a seventh-grade flight challenge, Neil introduced Bernoulli's principle to help students understand lift, providing scientific context for observed design outcomes.

Interview data further indicate that teachers were highly motivated to provide supplemental math and science instruction when students struggled with skills necessary for completing engineering tasks. This support most often took the form of targeted remediation in mathematics, including profit calculations, fractions, unit conversions, probability, and graphing. Teachers cited multiple reasons for emphasizing math and science content, including their own disciplinary backgrounds and a desire to reinforce content students were learning in core classes.

Teachers varied, however, in how deeply they chose to emphasize disciplinary instruction. Some teachers described intentionally limiting math instruction due to concerns about student anxiety or disengagement. Jim articulated this tension, explaining,*"anytime I would try to do what I call technical math, I shied away from it because the chaos or the confusion or the angst is not worth it."*

In contrast, other teachers described adjusting how math was presented rather than avoiding it altogether. Jeanette emphasized breaking content down to reduce frustration and maintain engagement, noting that her goal was to ensure that even students who struggled most could remain involved in the engineering work.

Finally, some teachers described intentionally allowing students' misconceptions to surface and lead to visible failure as a learning strategy. Joan explained that printing incorrectly sized 3D designs provided students with concrete evidence of the importance of careful measurement:

> *"…I kept saying, 'check your measurements,' and I could see some that were going to print out way too big. I said, I have to print it and let them see what it looks like when you don't check that."* (Joan)

Across classrooms, teachers' approaches to math and science integration reflected ongoing instructional decision-making shaped by student need, teacher background, and the practical demands of engineering design activities.

RQ2. What are teachers' perceptions of their students' skill and motivation levels for math and science during their implementation of STEM-ID**?**

Interview data indicate that teachers consistently perceived gaps in students' foundational mathematics knowledge as a challenge during implementation of the STEM-ID curriculum. Teachers most frequently described difficulties related to measurement, unit conversions, fractions, probability, and data representations such as histograms. These gaps were often identified as barriers that had to be addressed before students could meaningfully engage in engineering design tasks.

Ellen described students' unfamiliarity with core representations used in the curriculum:*"Yes, they were new to the idea of a histogram. They had no understanding of that… Measurement, oh my gosh. They'll be like, 'I never learned that.'"* (Ellen)

Similarly, Sally reflected on how assumptions about prior knowledge often did not hold, noting that concepts such as probability or unit conversion required explicit review before students could apply them within engineering contexts. Teachers emphasized the challenge of balancing curriculum pacing with the need to revisit foundational skills, particularly when students' mathematical understanding varied widely within the same classroom.

Teachers more frequently discussed limitations in mathematics than in science, often framing math as a more significant barrier to student progress. While some students were able to connect engineering tasks to prior experiences, such as science fair projects, many struggled to apply mathematical reasoning in authentic contexts such as budgeting, scaling, or spatial design. Teachers described providing additional scaffolding and simplifying tasks in order to reduce frustration and maintain engagement.

In addition to perceived skill gaps, teachers noted that students often entered engineering courses with expectations that differed from those of core academic classes. Some students expressed surprise or resistance when asked to engage in challenging math or science work within an elective or "connections" course. Jeanette described this reaction, stating, *"if the kids struggle in math, it is a barrier to the engineering classroom because some kids go into full shutdown mode… 'Why are we doing math in this class?'"*

Teachers responded to this resistance in different ways. Some chose to minimize math and science demands to maintain momentum, while others held high expectations and encouraged students to persist through discomfort. Several teachers described engineering problems as an opportunity to reframe math and science as useful tools rather than evaluative hurdles.
Across interviews, teachers consistently emphasized the motivational power of engineering contexts. By situating math and science as means to achieve tangible outcomes, teachers observed increased student persistence and willingness to engage in challenging tasks. Shannon described how students' engagement shifted during a design challenge, *"I saw these kids do more math on that Makeable challenge than ever before… because they wanted it printed, they did it. If they didn't know how, they'd actually ask me to show them."* She further noted that removing grading pressure allowed students to reassess their own abilities, observing that students who claimed to be "bad at math" often demonstrated strong computational skills when they were motivated by design goals.

Teachers also described how engineering activities helped students recognize the relevance of math and science beyond the classroom. Kathryn shared an interaction in which students connected kinetic energy concepts from a rollercoaster design challenge to science learning more broadly, reinforcing the idea that disciplinary knowledge could be applied across contexts.
Overall, teachers perceived engineering activities within STEM-ID as both revealing students' gaps in foundational math skills and providing a motivating context for addressing those gaps. While challenges related to student anxiety and skill variability persisted, teachers consistently described engineering as a space where students were more willing to engage with math and science when those disciplines were clearly connected to meaningful, hands-on outcomes.

RQ3. To what extent does participation in STEM-ID **impact students' standing on science and math anxiety, engagement, and interest?**

Data from students across six middle schools revealed statistically significant pre–post changes across all measured constructs. As shown in Table 3 below, mean scores increased from pre- to post-survey, indicating positive shifts in student outcomes. Items assessing mathematics and science anxiety were reverse-coded; therefore, lower mean scores reflect higher levels of anxiety, whereas higher mean scores indicate lower anxiety. These quantitative findings support the qualitative results, which documented students' initial struggles with foundational mathematics concepts and highlighted the role of instructional scaffolding in supporting student learning and engagement over time.

Table 3. Survey Results (n=305)

Survey Constructs	Pre		Post		Diff.
	M	SD	M	SD	
Academic Self-Efficacy	3.14	0.59	3.44	0.44	.30
Math & Science Anxiety	2.60	0.83	3.10	0.55	.52

Results indicated a statistically significant increase in students' academic self-efficacy from pre- to post-survey ($t = 10.23$, $p < .01$, $d = .58$), reflecting a moderate effect size. In addition, mathematics and science anxiety—reverse-scored such that higher values indicate lower anxiety—showed a significant improvement from pre to post ($t = 15.58$, $p < .01$, $d = .89$), representing a large effect size. Together, these findings suggest that students experienced increased confidence in their academic abilities alongside reduced anxiety related to mathematics and science over the course of the intervention.

Discussion

This study examined how middle school teachers approached mathematics and science integration while implementing a problem-based engineering curriculum and how students' academic self-efficacy and math and science anxiety shifted over the course of participation. Findings underscore both the promise and complexity of using engineering as a context for disciplinary integration in K–12 classrooms.

Consistent with prior research positioning engineering as a naturally integrative domain [1], [2], implementation of the STEM-ID curriculum provided a context for embedding mathematics and science instruction within engineering activities. Teachers introduced disciplinary instruction when gaps in foundational skills limited students' ability to engage in engineering tasks, particularly in mathematics. This pattern aligns with Bryan and Guzey's [9] characterization of integrated STEM instruction as a process that relies heavily on teachers' moment-to-moment instructional decision-making.

Teachers' approaches to math and science integration were shaped by their perceptions of student readiness, engagement, and anxiety. While some teachers emphasized disciplinary instruction as central to engineering learning, others moderated the depth of math and science instruction to avoid disengagement or shutdown among students who struggled in core academic classes. These findings reflect tensions documented in prior work on student engagement in elective or "connections" courses, where students may resist academic demands that resemble those of core subjects [11]. Rather than reflecting inconsistent implementation, these variations highlight the critical role of teacher judgment in balancing disciplinary rigor with attention to student affect.

Despite teachers' widespread perceptions of gaps in foundational mathematics skills, engineering activities were consistently described as motivating contexts for engaging students in math and science practices. Teachers observed that students were more willing to persist with challenging content when math and science were framed as tools for achieving tangible design outcomes rather than as evaluative endpoints. This finding reinforces prior research demonstrating that integrated and design-based STEM curricula can enhance student engagement by situating disciplinary learning within authentic problem-solving contexts [6], [7].

Quantitative results complement these qualitative findings, indicating statistically significant increases in students' academic self-efficacy and reductions in math and science anxiety over the course of the semester. These affective shifts are notable given teachers' descriptions of students' initial struggles with foundational skills and suggest that sustained engagement in engineering instruction may support positive motivational outcomes alongside disciplinary learning. Together, these results extend existing research on integrated STEM education by highlighting the affective benefits of engineering participation in addition to cognitive and engagement-related outcomes.

Several limitations should be considered when interpreting these findings. First, teacher interview data reflect perceptions of student skill and motivation, which may not fully capture students' experiences or learning trajectories. Future research could incorporate student interviews or classroom-based assessments to more directly examine how students perceive and experience math and science integration within engineering contexts. Second, integration practices varied across teachers and implementation years, making it difficult to isolate the effects of specific instructional strategies. Future studies could more closely examine how particular forms of math and science scaffolding relate to student outcomes. Finally, while this study documents positive affective shifts over a single semester, longitudinal research is needed to understand whether these changes persist and how engineering experiences influence students' longer-term engagement with math and science.

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References

[1] S.S. Guzey, T.J. Moore, and M. Harwell, M., "Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials," *Journal of Pre-College Engineering Education Research (J-PEER)*, vol. 6 (1), 2016, https://doi.org/10.7771/2157-9288.1129

[2] T.J. Moore, M.S., Stohlmann, H.H. Wang, K.M. Tank, A.W. Glancy, and G.H. Roehrig, "Implementation and integration of engineering in K-12 STEM education," in *Engineering in pre-college settings: Synthesizing research, policy, and practices,* 2014, Purdue University Press, pp. 35 – 60.

[3] G. Di Pietro, "The impact of Covid-19 on student achievement: Evidence from a recent meta-analysis," "Educational research review", vol. 39, 2023, https://doi.org/10.1016/j.edurev.2023.100530

[4] S. Kowalski, M. Kuhfeld, S. Peters, G. Robinson, and K. Lewis, "Technical appendix for: COVID's impact on science achievement: Trends from 2019 through 2024", September, 2024, NWEA, https://www.nwea.org/uploads/Tech_appendix_Science_achievement_COVID_Research_2024.pdf

[5] K. Lewis and M. Kuhfeld, "Recovery still elusive: 2023–24 student achievement highlights persistent achievement gaps and a long road ahead," July, 2024, NWEA, https://www.nwea.org/uploads/recovery-still-elusive-2023-24-student-achievement-highlights-persistent-achievement-gaps-and-a-long-road-ahead_NWEA_research_brief.pdf

[6] S. Anwar, M. Menekse, S. Guzey, and L.A. Bryan, " The effectiveness of an integrated STEM curriculum unit on middle school students' life science learning," *Journal of Research in Science Teaching,* vol. 59 (7), pp. 1204-1234, 2022, https://doi.org/10.1002/tea.21756

[7] E.P. Driessen, J. Wilhelm, M. Cole, A. Dunn, and K. Anderson, K., "The impacts of two curricula on middle-level students' engineering understanding," *The Journal of Educational Research,* vol. 116(1), pp. 1-16, 2023, https://doi.org/10.1080/00220671.2022.2158156

[8] M. Arık, M. and M.S. Topçu, "Implementation of engineering design process in the K-12 science classrooms: Trends and issues," *Research in Science Education,* vol. 52(1), pp. 21-43, 2022, https://doi.org/10.1007/s11165-019-09912-x

[9] L. Bryan and S.S. Guzey, "K-12 STEM Education: An overview of perspectives and considerations," *Hellenic Journal of STEM Education,* vol. 1(1), pp. 5-15, 2020, https://doi.org/10.51724/hjstemed.v1i1.5

[10] R. Lie, S.S. Guzey, and T.J. Moore, "Implementing engineering in diverse upper elementary and middle school science classrooms: Student learning and attitudes," *Journal of Science Education and Technology,* vol. 28(2), pp. 104-117, 2019, https://doi.org/10.1007/s10956-018-9751-3

[11] J.A. Fredricks, A.K. Parr, J.L. Amemiya, M.T. Wang, and S. Brauer, S, “ What matters for urban adolescents’ engagement and disengagement in school: A mixed-methods study,” *Journal of Adolescent Research,* vol. 24(5), pp. 491-527, 2019, https://doi.org/10.1177/0743558419830638

[12] M. Alemdar, J. Gale, J. Lingle, S. H. Newton, R. Moore, J. H. Rosen, & M. Usselman, M., “Students' Perceptions of a Middle School STEM Innovation and Design Course,” June, 2017 ASEE Annual Conference & Exposition.

[13] M. Alemdar, R. A. Moore, J. A. Lingle, J. H. Rosen, J. Gale, & M. Usselman, M, “The impact of a middle school engineering course on students‘ academic achievement and noncognitive skills”, *International Journal of Education in Mathematics, Science and Technology (IJEMST)*, 6(4), 363-380, 2018. DOI: 10.18404/ijemst.440339

[14] A. Field, *Discovering statistics using SPSS* (Third ed.): Sage publications, 2009.

[15] S.M. Glynn, G. Taasoobshirazi, and P. Brickman, “Science Motivation Questionnaire: Construct validation with nonscience majors,” *Journal of Research in Science Teaching,* vol. 46(2), pp. 127-146, 2009, doi:10.1002/tea.20267

[16] S.K. Gilmartin, E. Li, and P. Aschbacher, P, “Relationship between interest in physical science/engineering, science class experiences, and family contexts: Variations by gender and race/ethnicity among secondary students,” *Journal of Women and Minorities in Science and Engineering*, vol. 12(2-3), pp. 179-207, 2006, DOI**:** 10.1615/JWomenMinorScienEng.v12.i2-3.50

[17] B. Haiyan, W. LihShing, P. Wei, and M. Frey, “Measuring mathematics anxiety: psychometric analysis of a bidimensional affective scale,” *Journal of Instructional Psychology,* vol. 36(3), pp. 185-193, 2009.

[18] A. Bandura, *Self-efficacy: The exercise of control*, New York: W.H. Freeman, 1997.

[19] S.M. Glynn, and T.R. Koballa, Jr., “Motivation to Learn College Science,” in *Handbook of College Science Teaching,* J.J. Mintzes & W.H. Leonard (Eds.), Arlington, VA: National Science Teachers Association Press, 2006, pp. 25 – 32.

[20] H. Bai, L. Wang, W. Pan, and M. Frey, “Measuring mathematics anxiety. Psychometric analysis of bidimensional affective scale,” *Journal of Instructional Psychology*, vol. 31, pp. 185 – 193, 2009.

[21] M.B. Miles, A.M. Huberman, and J. Saldaña, *Qualitative data analysis: A methods sourcebook (4th ed.)*, SAGE Publications, 2018.