A Mixed Methods Evaluation of a Middle School LEGO®-based Hands-On STEM Workshop (Evaluation)

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Abstract

LEGO®-based activities are widely used in K-12 Science, Technology, Engineering, and Math (STEM) education as they support hands-on learning while being enjoyable and effective in teaching a wide range of scientific principles. Using LEGO® Technic™ and MINDSTORMS® EV3 components, we designed and facilitated a three-day interdisciplinary middle school workshop introducing laboratory automation, experimental chemistry, and engineering design through a series of hands-on activities. Student groups assembled three types of LEGO® lab equipment (syringe pump, orbital shaker, centrifuge), used each machine to automate three steps of a chemistry experiment (synthesis of calcium carbonate microparticles), and finally planned and prototyped modified designs of their lab equipment for different purposes. We evaluated the workshop using a mixed methods approach that combined student free-response reflections, facilitator observations, and a follow-up teacher interview with an exploratory survey administered before, immediately after, and three weeks after the workshop. While most survey items did not change significantly, the qualitative data provided insights into student experience. In particular, the chemistry activity appeared to elicit strong engagement, whereas the students unfamiliar with the Technic™ pieces experienced reduced confidence in building with LEGO®. Based on these insights, we offer practical guidance for designing interdisciplinary STEM workshops that balance structure, autonomy, and difficulty in middle school settings.

Introduction

In recent years, there has been a growing interest in introducing engineering concepts and practices to younger learners. According to the National Academy of Sciences, the four main goals for K-12 engineering education include developing engineering literacy, improving math and science achievement, improving college and career readiness, and preparing students for post-secondary engineering programs [1]. More broadly, early engineering experiences may help students connect technical problem solving with everyday decision making, collaboration, and participation in society [1].

We developed a three-day interdisciplinary workshop for middle school students with the objective of introducing a variety of STEM topics through a positive, interactive, and hands-on classroom experience. We facilitated the workshop during regular class hours over approximately four weeks and examined the workshop through a combination of observations, pre- and post-workshop surveys, and an interview with the teacher to explore how the students experienced the various workshop activities. We found that the students were most engaged during the experimental chemistry lesson but struggled with unfamiliar LEGO® Technic™ components during assembly. Our mixed methods evaluation of student experience and workshop implementation have implications for short-term workshop curriculum development in real middle school settings.

Background

An active learning approach leverages the students' curiosity to learn, while encouraging collaboration and communication with peers, making the learning experience more meaningful [2],[3]. It is also known to improve performance on exams across all STEM disciplines, class sizes, and course levels [4]. Hands-on learning is a form of active learning that offers students opportunities to apply concepts learned in class to practice [5], [6]. Interactive activities include experiments or projects and have been associated with improved understanding of the material [7], motivation, and self-efficacy across various STEM contexts [8].

According to Bandura's social cognitive theory, self-efficacy refers to an individual's judgment of their capability to execute actions needed to achieve a specific goal, and it influences which tasks they perceive as manageable [9]. In social cognitive career theory, self-efficacy is one of the key variables that determines students' academic interest, career choices, and persistence when faced with obstacles [10], and is also influenced by past performance, success of others similar to oneself, verbal encouragement, and physiological reactions [9], [10]. Self-efficacy has been evaluated in STEM education settings with the STEM competency beliefs survey [11], designed for students aged 10-14. Studies have used this tool to measure students' self-efficacy in topics such as computation [12], computer science [13], coding [14], and the impact of a game design intervention [15]. Other studies have investigated how students' beliefs about their own abilities relate to STEM attitudes, motivation, and career interests [16], [17], [18], [19], [20].

Given the importance of career interests and self-efficacy in STEM learning, we developed an interdisciplinary workshop to introduce multiple STEM topics through a hands-on experience and examine how students respond to it. Combining data collected through observations, students' post-workshop reflections, and teacher feedback with an exploratory survey administered before and after the workshop, we identified insights on developing interdisciplinary hands-on STEM workshops for middle school classrooms for enhanced student experience and workshop outcome.

For our hands-on STEM workshop, we used LEGO® components, which are reconfigurable construction elements that have been used with students ranging from kindergarten [21] to undergraduate level [22]. LEGO®-based activities are common in K-12 STEM education [23] and provide a flexible platform for problem solving and model facilitated learning [24], [25], [26], [27]. Previous work has reported positive effects of LEGO®-based activities on classroom engagement and attitudes towards STEM in engineering courses [28]. LEGO® systems have been most commonly used to teach robotics and programming [29], [22], but they have also been used as "mindtools" [30], [31] that support conceptual learning [32], while being fun and engaging [21], [31], [33], [34]. Regarding hands-on STEM learning, the high modularity of LEGO® components enables students to enjoy rapid cycles of design, testing, and redesign [29].

In this study, we used LEGO® Technic™ pieces and LEGO® MINDSTORMS® EV3 components to introduce students to three topics: robotic assembly and operation (technology), experimental chemistry (science), and engineering design (engineering). Because the workshop was interdisciplinary rather than exclusively engineering-focused, we designed each day to engage a different dimension of engineering literacy [1]. Day 1 engaged students in procedural and technical reasoning through assembly of complex artifacts – practicing the systematic, instruction-following cognition that underpins engineering implementation. Day 2 situated those artifacts within a scientific application, giving students an experiential understanding of how engineered tools enable scientific inquiry and why technology matters in practice. Day 3 introduced the iterative engineering design process more directly through open-ended prototyping. We therefore interpret the survey items not as uniform measures of engineering competency and career interests, but as broad indicators of attitude. In this paper, we detail the workshop lesson plans and synthesize the qualitative data (observations, student' free-response reflections, and teacher interview) with the exploratory survey findings to identify strengths and weaknesses of this workshop and propose future curriculum revisions and study design.

Workshop Lesson Plan

In a previous study, LEGO® Technic™ pieces and MINDSTORMS® EV3 components were used to develop and test three common automation tools used in the life science lab [35]. Based on the three LEGO® lab equipment ("lab robots"), we developed a three-day LEGO®-based hands-on STEM workshop for middle school students.

We visited the class four times, with four independent sections participating. The workshop was conducted during the first three visits (Fig. 1), each lasting $\sim$ 90 minutes during regular class hours. A team of three instructors rotated workshop facilitation. In total, twelve sessions were conducted, where two sessions were led by one instructor, six sessions were facilitated by two instructors, and four sessions were facilitated by all three instructors.

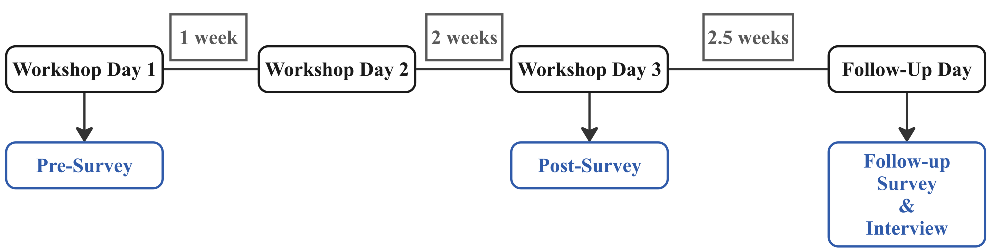

Figure 1: Workshop timeline.

Each of the three workshop days was designed with intentional variation in disciplinary focus and degree of open-endedness: Day 1 developed procedural and technical reasoning through structured robot assembly, Day 2 contextualized engineering within real-world scientific practice in a guided but more improvisational experimental format, and Day 3 introduced open-ended engineering design. Together, they were intended to build engineering literacy through technical problem solving, cross-disciplinary connection-making, and design thinking [1]. On the first workshop day, students worked in pairs or groups of three to assemble the lab robots according to the instructions. On the second day, students interacted with facilitators in groups to use their robots to perform a chemistry experiment. On the last day, students imagined and sketched new robots they could build by modifying the original lab robots and then assembled and tested them. On the first and last days, we reserved fifteen to twenty minutes for survey completion. We focused most of the workshop time on hands-on, self-led activities, as prior work reported that project-based, hands-on work is more effective than lectures [4], [6], [36]. The final visit took place approximately three weeks after workshop completion to administer the follow-up survey and conduct an interview with the teacher.

Workshop Day 1: Build

The first day focused on an introduction to the workshop, LEGO® robotics, and the three lab robots the students would be working with. Before beginning the workshop activities, students had the opportunity to ask questions about the study and the workshop and provide assent. Each lab robot was divided into smaller sub-assemblies that were later combined into the full device. Students worked in pairs or groups of three, depending on class attendance, to assemble a sub-component following an instruction manual. The primary goals for this activity were to foreshadow the lab equipment needed for the Day 2 chemistry experiments, familiarize students with the LEGO® Technic™ components to motivate the Day 3 design activity, and give students a hands-on, team-based experience highlighting the collaborative nature of engineering. While Day 1 was not structured as an open-ended design lesson, the robot assembly engaged students in the systematic, specifications-driven reasoning that is foundational to engineering practice.

Workshop Day 2: Make

On the second day, students used the three lab robots they assembled to synthesize calcium carbonate ($CaCO_3$) microparticles. This hands-on experiment was based on an established procedure [37], but modified for the classroom activity (Tables 1 and 2). Each group utilized the LEGO®-based syringe pump and orbital shaker to mix two solutions, and we added a separation step at the end to allow students to explore centrifugation using the LEGO® microcentrifuge.

Table 1: Materials required for calcium carbonate ($CaCO_3$) synthesis.

Material	Amount (per group)
0.33 M sodium carbonate	5 mL
0.33 M calcium chloride	5 mL
10 mL syringe	2
Syringe tip and tube	1
20 mL scintillation vial	1

We began the workshop with an introductory discussion about chemistry, chemical reactions, and where we see chemical reactions in our daily lives. Then, we reviewed the three lab robots and their functions and completed the introductory lesson with an introduction to $CaCO_3$. Depending on section size, the class was organized into one to three groups, each led by at least one instructor. All groups were given three fully assembled lab robots, a LEGO® MINDSTORMS® EV3 brick, and connection cables. We began the experimental procedure with a demonstration of how to use the EV3 brick, allowing students to experiment with different functions and operation speed. Each instructor then guided students through the procedure outlined in Table 2, ensuring that all students took turns contributing to the experiment through hands-on engagement, such as drawing liquids and setting the lab robot operation time and speed. All materials were safe and non-toxic, and the procedure did not involve any sharps or needles.

Table 2: Experimental procedure followed during the workshop, which was based on previous work [37], but modified to utilize the LEGO®-based equipment [35].

Step	Procedure
1	Use a syringe to dispense 5 mL of calcium chloride solution into a 20 mL scintillation vial.
2	Load a different syringe with 5 mL of sodium carbonate solution.
3	Place the syringe with sodium carbonate solution into the syringe pump.
4	Connect the tube to the tip of the syringe and make sure the other end of the tube is placed inside the scintillation vial.
5	Set the syringe pump to dispense at speed = 9.
6	Run the syringe pump until all the liquid is dispensed into the scintillation vial.
7	Close the cap of the vial and securely place the vial in the orbital shaker.
8	Set the orbital shaker to run at speed = 9 for 5 minutes.
9	Watch the mixture turn from clear to white! The white solids at the bottom of the vial are the calcium carbonate particles.

A key pedagogical goal of Day 2 was to close the loop between Day 1 assembly and the real-world purpose of the devices the students had built. This activity was intended to give students a direct experiential encounter with a real-world application of the devices they had constructed.

Workshop Day 3: Design

On the last day of the workshop, students designed and tested their own robots by modifying the previously assembled lab robots. During the introductory discussion, we provided students with examples of different types of LEGO® robots and reviewed the mechanical motions performed by the lab robots (linear back-and-forth motion of the syringe pump, circular shaking of the orbital shaker, and rapid rotation about a central axis of the microcentrifuge). We led a discussion to brainstorm other machines that could move based on these motions. Students then got into groups and sketched at least one idea of a machine they could make by modifying the lab robots. Afterwards, they were encouraged to take the lab robot apart and reuse or add new pieces to prototype their designs. At the end of the workshop, we provided students with time to clean up and complete the post-workshop survey.

Workshop Day 4: Follow-Up Visit

We visited the class approximately three weeks after workshop completion to administer a follow-up survey. To minimize disruption of regular class activities, we provided no additional instruction during the follow-up visit. Instead, we administered the survey and conducted a semi-structured interview with the teacher to learn more about the class and reflect on the workshop.

Methods and Analysis

We facilitated a workshop at a medium-sized suburban middle school during normal school hours and evaluated student responses to the workshop using a mixed methods approach. Quantitative survey data were used as exploratory indicators of engineering career interest and workshop-aligned confidence, while qualitative free-response reflections, facilitator observations, and a teacher interview were used to contextualize how specific features of the curriculum shaped student experience. The study was reviewed and approved by the University of Colorado Institutional Review Board (Protocol #24-0737).

Participants

We facilitated the workshop in four sections of an elective course. Although more students were enrolled, the analytic sample included 32 consenting students who participated in the full workshop sequence without absences. Demographic information reported by students and guardians is summarized in Table 3. All demographic questions were optional fill-in-the-blank items.

Table 3: Self-reported participant demographics.

Category	Group	n (%)
Gender Identity	Male-Identifying	19 (59%)
	Female-Identifying	7 (22%)
	Other/Not Disclosed	6 (19%)
Grade	Grade 8	17 (53%)
	Grade 7	14 (44%)
	Grade 6	1 (3%)
Ethnicity	White	12 (38%)
	Mixed	3 (9%)
	Asian	1 (3%)
	Hispanic	1 (3%)
	Not Disclosed	15 (47%)

Survey Design

We developed an exploratory survey (Table 4) by adapting selected items from two published instruments: the STEM career interest survey (STEM-CIS) [38] and STEM competency beliefs survey [11]. The original instruments contain 11 and 12 items, respectively. Administering both in full along with the free-response questions on workshop experience, would have produced a survey that was likely too long for a middle school classroom. To reduce survey length and cognitive load, we selected five items from the STEM-CIS [38] and five items from the competency beliefs survey [11], then adapted the wording to better align with workshop content and maintain a consistent tone across items. We also adjusted the adapted STEM-CIS [38] items to four-point Likert scale to maintain consistency with the competency beliefs survey [11] and remove a neutral midpoint. While the resulting instrument combined selected and modified items without being formally revalidated, we did not treat it as a validated measure of career interest or self-efficacy. Instead, we used it as an exploratory instrument containing two analytic groupings: engineering-interest attitude items (Q1-Q5) and workshop-aligned confidence items (Q6-Q10).

Table 4: Workshop survey.

		Question	Source
Included in the pre-/post-/follow-up surveys.	Q1	I am excited by engineering.	Modified from [38]
	Q2	I believe I can get a good grade in my engineering classes.	
	Q3	I am motivated to work hard in my engineering class.	
	Q4	I am curious to learn more about engineering.	
	Q5	I think I would enjoy a career that involves engineering.	
	Q6	I feel confident that I can understand engineering information.	Modified from [11]
	Q7	I feel confident that I can figure out how to fix things that don't work.	
	Q8	I feel confident building things with LEGO®s.	
	Q9	I feel confident designing new things with LEGO®s.	
	Q10	I feel confident conducting chemistry experiments.	
Only included in the post-workshop survey.	Q11	I think the workshop was easy.	
	Q12	I think building the LEGO® robot was easy.	
	Q13	I think conducting a chemistry experiment was easy.	
	Q14	I think I learned a lot of new things through this workshop.	
	Q15	It was easy to stay focused on the workshop.	
	Q16	Overall, I enjoyed participating in this workshop.	
	Q17	I want to participate in another workshop like this in the future.	
	Q18	What is one thing you learned in this workshop?	
	Q19	What is one question you have for your instructors?	
	Q20	How can we make this workshop better for you next time?	
	Q21	Do you have any other feedback for your instructors?	

We administered the survey three times: a pre-workshop survey ("pre-survey") at the beginning of the workshop, a post-workshop survey ("post-survey") immediately at the end of the three-day workshop, and a three-week follow-up survey ("follow-up survey"). The pre-survey and follow-up survey each contained the ten four-point Likert-scale questions (Q1-Q10). The post-survey included Q1-Q10, as well as seven additional Likert-scale items related to workshop experience and difficulty (Q11-Q17) and four free-response questions (Q18-Q21) intended to capture student reflections, questions, and suggestions. For clarity, Table 4 is organized by analytic grouping: Q1-Q5 are engineering interest, Q6-Q10 are workshop-aligned confidence, Q11-Q17 are post-workshop experience, and Q18-Q21 are free-response items. Because the adapted survey was not formally revalidated, we report item groupings for transparent reporting and interpretation.

Interview

During the follow-up visit, we conducted a semi-structured interview with the teacher. We prepared an interview protocol (Table 5) to gather contextual information about the course and students, and to obtain feedback on the workshop curriculum. We treat this interview as process-evaluation data to supplement student survey results and identify opportunities for curriculum revision.

Table 5: Semi-structured interview protocol.

Topic	Questions
Introduction	Tell us a little about yourself. What classes are you teaching this semester and what other classes have you taught in the past? What other classes have you taught/are you teaching What led you to become a middle school teacher?
Class Details	Can you tell us a little about your class? What does a typical day in your class look like?
Workshop	How do you think the workshop went for your students? What about our workshop seemed to work and what could we have done differently? Did you notice changes in your students' engagement with course materials after our workshop? If this workshop was offered next academic year (as an elective), would you recommend it to your students? If you could change the curriculum, what changes would you make?

Statistical Analysis of Survey Data

While 32 students participated in the study, two students were absent during the follow-up visit, yielding a follow-up sample of 30. For analysis involving the follow-up survey, we restricted the paired sample accordingly. Three survey responses were invalid because they were unanswered or contained written-in values inconsistent with the response format; these were imputed using the median response for the corresponding item. Because Likert-scale responses were ordinal and non-normally distributed by the Shapiro-Wilk test, we used nonparametric analyses.

We conducted Wilcoxon signed-rank tests for item-level comparisons across surveys for Q1-Q10 and applied the Holm-Bonferroni method to control the family-wise error rate (FWER) across multiple comparisons. We also calculated within-student response changes (Δn) between data collection points. Furthermore, the qualitative post-survey responses (Q18-Q20) were grouped into broad thematic bins based on recurring patterns. These items were then used for exploratory subgroup comparisons using Mann-Whitney U tests.

Results

We obtained data through student surveys, post-survey free responses, facilitator observations, and a semi-structured interview with the teacher conducted three weeks after workshop completion. While most survey items did not show significant change after correction, analysis revealed a significant decrease in students' confidence in building with LEGO®. However, students appeared to enjoy the workshop overall, with the chemistry activity standing out as especially engaging.

Survey Results

The unadjusted p-values suggested several significant item-level differences across surveys, but only one item remained statistically significant after applying the Holm-Bonferroni method: Q8, "I feel confident in building things with LEGO®s," decreased from pre- to post-survey. We therefore treat the remaining item-level variances as exploratory rather than conclusive. The changes in mean scores for each survey item are summarized in Table 6.

Confidence in Building with LEGO® Bricks

For Q8, which states, "I feel confident in building things with LEGO®s," we found a significant decrease from the pre-survey (M = 3.56) to the post-survey (M = 3.19), with an adjusted p-value of 0.0027 (Fig. 2). We interpret this result not simply as a negative outcome, but as evidence that supports our observations that students' prior familiarity with conventional LEGO® kits may not have prepared them for the greater difficulty of working with the unfamiliar Technic™ components.

Workshop Experience

We assessed student experience through eleven post-workshop questions (Q11-Q21) related to difficulty, enjoyment, learning, and open-ended reflection (Table 4). The first seven items (Q11-Q17) were measured on a four-point Likert-scale, and the remaining four items (Q18-Q21) were short-response prompts. Table 7 reports the descriptive statistics for Q11-Q17. Seven responses were imputed because they contained multiple selections or written-in values. Overall, these results indicate that students viewed the workshop positively, believed they learned new material, and generally found the activities manageable. At the same time, "it was easy to stay

Table 6: Mean ± standard deviation of the quantitative survey items for the pre- (n = 32), post- (n = 32), and follow-up (n = 30) surveys, where 1 is "Strongly Disagree" and 4 is "Strongly Agree."

	Question	Pre-Survey	Post-Survey	Follow-up Survey
Q1	I am excited by engineering.	3.13 ± 0.82	3.16 ± 0.83	3.13 ± 0.88
Q2	I believe I can get a good grade in my engineering classes.	3.31 ± 0.88	3.38 ± 0.82	3.37 ± 0.75
Q3	I am motivated to work hard in my engineering class.	3.19 ± 0.77	3.06 ± 0.90	3.03 ± 0.95
Q4	I am curious to learn more about engineering.	3.00 ± 0.87	3.06 ± 0.97	3.17 ± 0.90
Q5	I think I would enjoy a career that involves engineering.	2.63 ± 1.11	2.91 ± 1.01	2.87 ± 1.02
Q6	I feel confident that I can understand engineering information.	3.13 ± 0.78	3.13 ± 0.82	3.43 ± 0.72
Q7	I feel confident that I can figure out how to fix things that don't work.	3.13 ± 0.78	3.34 ± 0.64	3.10 ± 0.79
Q8	I feel confident building things with LEGO®s.	3.56 ± 0.75	3.19 ± 0.85	3.37 ± 0.80
Q9	I feel confident designing new things with LEGO®s.	3.47 ± 0.71	3.13 ± 0.93	3.30 ± 0.74
Q10	I feel confident conducting chemistry experiments.	3.22 ± 0.82	3.22 ± 0.82	3.30 ± 0.82

focused on the workshop" received the lowest mean score, indicating room to improve pacing, structure, or autonomy. Taken together, these post-workshop items suggest that positive overall enjoyment can coexist with moments of confusion or loss of focus, an interpretation that aligns well with both the teacher interview and facilitator observations.

Interview

At the end of the follow-up visit, we conducted a semi-structured interview with the teacher to learn more about the course context, previously completed projects, and suggestions for future iterations. The teacher reported that students appeared most engaged on Day 2, which combined hands-on participation with a relatively structured procedure. In contrast, Day 1 appeared to be the most challenging because the lab robot assembly was complex and sometimes confusing, particularly for students who were unfamiliar with Technic™ components. The teacher also noted that the chemistry content was new for many students as experimental chemistry had not yet been introduced in their regular curriculum.

When asked to share insights on popular class projects that had been completed earlier in the semester, the teacher shared two common features: (i) students produced a tangible artifact they

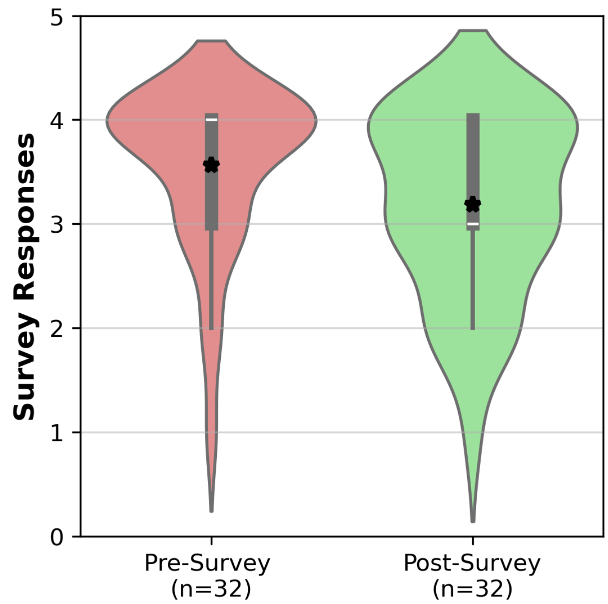

Figure 2: Responses to Q8, "I feel confident building things with LEGO®s," for the pre-survey (red) and post-survey (green). Asterisks denote the mean response values.

could take home and (ii) the activity included decision points that fostered student autonomy and accommodated different interests. These observations help explain why some parts of the workshop were experienced more positively than others and provide actionable guidance for future redesign.

Discussion

Our observations during workshop facilitation aligned with the teacher's account of the workshop. Both sources pointed to two recurring themes: unfamiliar LEGO® Technic™ pieces often introduced confusion during assembly, whereas the chemistry experiment elicited higher levels of student engagement. Student free-response answers also showed curiosity about technical topics beyond the workshop itself. We close by discussing challenges of facilitating the workshop during regular class time and propose directions for future curriculum modification and study design.

Perceived Impact

The teacher explained that the assembly portion of the workshop appeared to have reduced engagement and increased confusion, and our own observations substantiated this interpretation. The LEGO® Technic™ liftarms, pins, and axles differ substantially from the components commonly found in LEGO® kits. We therefore hypothesize that some students started the workshop with expectations shaped by prior LEGO® experience and then encountered challenges that were more difficult, less intuitive, and more visually demanding than expected. We also observed that any visual mismatch between the instruction manual and the available pieces, such

Table 7: Mean $\pm$ standard deviation of the quantitative post-survey items (n = 32), where 1 is "Strongly Disagree" and 4 is "Strongly Agree."

	Question	Mean
Q11	I think the workshop was easy.	3.00 ± 0.71
Q12	I think building the LEGO® robot was easy.	3.16 ± 0.71
Q13	I think conducting a chemistry experiment was easy.	3.09 ± 0.68
Q14	I think I learned a lot of new things through this workshop.	2.97 ± 0.85
Q15	It was easy to stay focused on the workshop.	2.69 ± 0.68
Q16	Overall, I enjoyed participating in this workshop.	3.13 ± 0.89
Q17	I want to participate in another workshop like this in the future.	3.06 ± 0.90

as color, caused avoidable confusion. The significant decrease in survey item Q8, confidence in building things with LEGO®, is consistent with this interpretation.

While we attempted to reduce assembly difficulty by dividing each robot into smaller sub-assemblies, in practice, this simplification may have reduced students' sense of ownership over a complete artifact, since many students did not immediately see how their sub-assembly contributed to the final device, consequently lowering motivation and interest. Based on these observations, we suggest that future iterations should simplify device assembly, preserve clear links between student effort and finished artifact, and align the visual instructions more carefully with the pieces used in the workshop.

Our observations on the second workshop day also aligned with the teacher's account, indicating higher levels of interest and engagement with the material. We observed students spinning around the classroom, mimicking the motion of a centrifuge, while expressing curiosity about centrifugation speed. Students asked facilitators questions about mechanical aspects of the devices such as gear ratio and about other equipment that help scientists in real laboratories. Several students explicitly compared manual liquid handling with the LEGO® syringe pump and used that comparison to reason why scientists use instrumentation. These observations indicate that the students were able to connect the workshop activities to real-world scientific and engineering practice.

On the third day, we observed that students were able to explain and sketch design ideas, indicating they could engage in some aspects of the engineering design process. Most students envisioned diverse types of robots; at the same time, some students became discouraged when their prototypes did not look or function as expected. Facilitators used these moments to emphasize that malfunction is an inevitable and important part of the prototyping process. Because this lesson was intentionally more open-ended and less structured, students progressed at different speeds, which may have contributed to lower level of student engagement. This observation suggests that autonomy was promising but may need more scaffolding to ensure that all students remain engaged, interested, and productive throughout the design activity.

The quantitative post-survey items (Table 7) suggest that students generally perceived the workshop positively, even though staying focused was relatively challenging. The free-response answers, however, showed encouraging trends: 19% of the students asked substantive follow-up questions about robotics, chemistry, and mechanical design, including questions such as "Could it be possible to make other kinds of LEGO® robots that do chemistry?", "What would happen if you extended the arms on the centrifuge?", "How do you make a motor?" These questions show that some students left the workshop with curiosity that extended beyond lesson completion. Because these questions were recorded after the final workshop activities, they also suggested that students retained enough interest from earlier sessions to continue reflecting on the underlying science and engineering.

In conclusion, the qualitative and quantitative findings suggest that structured, hands-on activities with visible outcomes appeared to support engagement, whereas unfamiliar materials and open-ended tasks without sufficient structure reduced confidence and interest. These patterns offer practical insight into how interdisciplinary STEM workshops can be better designed for middle school students, even in the absence of strong evidence for short-term change in STEM career interest and self-efficacy.

Limitations and Future Work

We acknowledge several limitations associated with implementing the workshop during regular class time rather than as a separate extra-curricular program. First, a larger survey would improve statistical power and enable more stable subgroup analysis. Second, a more deliberate, stratified sampling method may support future investigation of workshop impact on different demographic groups. Third, the facilitators varied across sections because of scheduling constraints. Although we did not observe a direct facilitator effect in the present study, future work should seek more consistent implementation conditions.

A central limitation of this study is the survey itself. Although it was adapted from two validated instruments [11], [38], we selected a subset of items to reduce survey length, modified the wording to align with workshop content, and changed one source instrument from a five-point to a four-point Likert scale. As a result, the instrument should not be interpreted as a validated measure of career interest or self-efficacy. This limitation is important because the survey items span multiple domains, including engineering, LEGO® building and design, troubleshooting, and chemistry experimentation. Additionally, the wording of some items, such as the reference to "engineering information" in Q6 may not have been interpreted consistently by middle school students, further motivating instrument revisions. We therefore treat the quantitative findings as exploratory indicators rather than definitive evidence. Future work should either validate a workshop-specific instrument or use the original instruments in unmodified form.

Our $\sim$4.5-hour long workshop introduced students to multiple STEM dimensions, but it did not provide enough time to develop each topic in depth. In particular, while the workshop included an engineering-oriented design day, not every workshop component was equally centered on engineering design, which matters when interpreting the engineering-related survey items. Future iterations should better define the lesson objectives of each day, equally distribute the time spent on each focus area, and provide a more explicit structure around both the scientific method and engineering design process.

For future studies, we propose several modifications to curriculum and study design. First, curriculum difficulty can be better aligned with learner level by either simplifying the robot designs for middle school students or by implementing the current curriculum for secondary school students. Simpler assemblies using more familiar LEGO® components may reduce confusion and preserve confidence, especially if each student can more clearly connect their effort to a finished device. Second, deeper engagement may be promoted by increasing instructional time, narrowing the thematic scope, or both. More time could allow students to move beyond following procedures and into more rigorous scientific inquiry and iterative engineering design. Third, adding more structure and support for autonomy in the workshop curriculum may help increase student achievement and engagement [39]. Fourth, the introductory framing of the workshop should be redesigned to better cultivate curiosity and clarify why robots matter in real scientific or engineering practice. Finally, further studies should pair a more refined curriculum with either a validated survey or a rigorously developed workshop-specific instrument, which may better support comparisons across groups or longitudinal studies.

Conclusion

We conducted a three-day interdisciplinary STEM workshop in which LEGO® Technic™ and MINDSTORMS® EV3 components were used to introduce students to robotics, experimental chemistry, and engineering design. Using a mixed methods approach, we found little evidence for significant changes in students' self-efficacy and career interests, but we found a significant decrease in students' confidence in building with LEGO®. When interpreted alongside post-workshop reflections, facilitator observations, and a teacher interview, we found that unfamiliar LEGO® Technic™ components introduced unexpected difficulty, but the chemistry activity appeared to yield improved engagement and left some students with an increased level of curiosity. We therefore argue that the principal contribution of this study lies in its practical insight into workshop curriculum and study design: interdisciplinary STEM workshops for middle school learners may benefit from simple and visually consistent building tasks, well-structured guidance for open-ended design activities, and closer alignment between intended outcomes and measurement tools. Rather than demonstrating a significant change in student interest and confidence, this study helps clarify how workshop structure, material familiarity, and activity design can impact student experience in short-term STEM interventions.

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