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Research Article

Enhancing high school students' mathematics achievement and skills development through integrated STEM-PBL: A collaborative action research study

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ABSTRACT

Science, technology, engineering, and mathematics (STEM) approach and project-based learning (PBL) can be integrated as complementary teaching method to actively engage students in addressing authentic challenges within an educational setting. This study aimed at developing students' skills as they work on their practical projects and at determining whether integrating the STEM-PBL method can enhance students' performance in applying mathematics, particularly geometrical concepts, for solving real-life problems. Employing a qualitative collaborative action research case study design, the study followed cycles of planning, action, observation, and reflection with ten high school students working on a smart house project in makerspace lab. Data were collected through geometry concept knowledge test and structured observation checklists. Results show a significant improvement in students' conceptual understanding and skills development in areas such as problem solving, research, communication, and collaboration. These findings highlight the potential of STEM-PBL integration to improve mathematics achievement and suggest the need for curriculum reform and teacher professional development to support STEM education.

Keywords: STEM education, project-based learning, collaborative action research, mathematics achievement, skill development, geometry

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education has generated considerable attention in the past twenty years. Integrating STEM subjects appears crucial in developing 21st century skills and abilities, also known as STEM skills (Anderson & Li, 2020), which are applicable in real-world problem-solving (Berisha & Vula, 2021; Dare et al., 2021; Tytler, 2020). Moreover, the different perspectives on STEM education remain a central point in several research studies (Cianca, 2020; Stehle & Burton, 2019; Subramaniam & Mok, 2023). Diverse academic disciplines strive to tackle distinct real-world problems and gain knowledge through everyday practices and situations. STEM education is a progressive approach that encourages the use of transdisciplinary educational programs for students (Corlu et al., 2014).

Additionally, STEM education initiatives aim to improve students' access to resources and interdisciplinary educational programs, fostering their critical thinking skills, problem-solving skills, and quick adaptation to technological advancements (Hamad et al., 2024). STEM education seeks to provide students with the necessary skills for the current workforce and improve their understanding of mathematical and other concepts by creating collaborative learning environments and integrating practical applications from real-world examples.

An increasing number of nations have demonstrated a preference for STEM education, which has resulted in the creation of curriculum that aims to achieve crucial outcomes both within and outside of classrooms. Given the significant global interest in STEM education and the extensive initiatives focused on developing STEM curricula, it is crucial to prioritize the enhancement of the STEM teaching approach through proper and effective professional development (Morris et al., 2021). Additionally, studies have demonstrated that STEM education aids students in achieving their pre-university goals, including the development of lifelong learning skills (Bybee, 2013) and equipping them to navigate diverse social and cultural environments, thereby addressing broader educational objectives (Kelley & Knowles, 2016). Honey et al. (2014) stated that integrated STEM education could assist in two areas: learning and achievement, as well as interest and identity. It could also help students learn more about concepts in different subjects, especially math, even though there isn't much evidence to show that a STEM approach improves math achievement (Honey et al., 2014).

However, English (2016), asserts that the effectiveness of STEM integration on math achievement depends on the method of integration as well as the types of assistance incorporated into the process and provided through appropriate training. He has suggested implementing modeling in STEM contexts and engineering environments, focusing on deep content comprehension, skill development, and enhancing content and processes through the generation of new problems. Even Maass et al. (2019), in their study, examined the role of mathematics and the possibility of advancing its position within interdisciplinary STEM education. In addressing this issue, they discussed three areas, attention to which can advance the role of mathematics in the field of STEM education:

(1) 21st century skills,

(2) mathematical modeling, and

(3) responsible citizenship education, using appropriate approaches for teaching and learning.

Project-based learning (PBL) seems to be an effective teaching and learning method within an integrated STEM approach. It allows students to engage in practical real-world problems and interdisciplinary projects (Evenddy et al., 2023) that require them to apply STEM knowledge and skills to solve complex problems or face authentic challenges (Dacumos, 2023). By integrating PBL into STEM education, students gain a more profound comprehension of STEM principles while also developing critical thinking, collaboration, communication, and problem-solving skills that are necessary for success in the 21st century (Stehle & Burton, 2019). Therefore, both STEM and PBL emphasize hands-on, inquiry-based learning experiences that foster meaningful engagement and more profound educational achievements for students (Capraro et al., 2013).

According to Fairweather (2008), a significant portion of research in the field of STEM education emphasizes the importance of empirical data in promoting effective educational innovations. The fundamental claim is that STEM teachers are reluctant to change their teaching methodology unless there is strong proof that the suggested alternative method is superior and more effective than the previous methodology (Nadelson et al., 2013). Li and Schoenfeld (2019) have demonstrated that we should not confine the understanding of mathematics to a static set of knowledge or skills but rather highlight the dynamic nature of its teaching instruction by elucidating the essential steps for the development and implementation of teaching methods.

The purpose of this study was to analyze whether the integration of the STEM-PBL method can improve students' achievement in applying mathematical concepts, especially geometrical concepts, in solving mathematical problems, as well as foster and develop their skills as they carry out their hands-on projects.

LITERATURE REVIEW

Mathematics in Integrated STEM Education

In recent years, many studies have emphasized the advantages of integrating the teaching and learning of STEM. STEM education, as defined by Bybee (2013), is the integration of two or more STEM disciplines to enable students to use their subject knowledge and create links between them to understand or solve real-world problems. Cianca (2020) defines STEM education as a teaching method that emphasizes inquiry, reasoning, collaboration, and application in real-world contexts. Berisha and Vula (2021) highlight the significance of collaboration in STEM, emphasizing its crucial role in nurturing the critical skills essential for the 21st century.

STEM education poses unique challenges due to the diversity of cultures, epistemologies, practices, and expectations found within each represented field (Townley, 2020). With an emphasis on the conceptualization of mathematics in this integration, Baldinger et al. (2020) have examined the literature on integrated STEM teaching in secondary schools. Beyond this study, integrated STEM education views mathematics less as a location for conceptual mathematical learning and more as a tool for scientific inquiry. Similarly, Fitzallen (2015) and Walker III (2017) claim that mathematics often functions as a problem-solving tool in the fields of science or engineering. Building on this perspective, Kavitha and Kareem (2025) show that STEM integration stimulates students' creativity and problem-solving skills by embedding math within authentic investigations rather than isolated theory lessons. According to Kumar and Hasio (2007), many universities in the last decade have created new opportunities through engineering courses where teamwork skills such as writing, individual presentations, and problem solving are part of receiving the diploma.

On the other hand, Oldknow (2010) argues that the establishment of STEM education offers a great opportunity for mathematics to embrace and include technology by engaging students as well as inspiring them in the use and application of mathematics and the exploration of mathematical concepts. Engaging students in challenging tasks fosters their active participation and involvement in the learning process, driven by their intrinsic motivation to overcome difficulties and their curiosity to find solutions (Leikin & Elgrably 2020). Although Wieselmann et al. (2022) have identified several weaknesses in the quality of the curriculum, it is evident that incorporating real-world motivational settings with aspects of authenticity effectively captivates students and showcases the advantage of integrating STEM subjects. Therefore, it is necessary for STEM education to serve distinct educational requirements and extend beyond simply introducing tangible STEM-related activities into a curriculum that needs to be reliable (Hobbs et al., 2018).

According to Tytler (2020), recent research shows that contemporary education increasingly emphasizes STEM education, particularly the importance of this approach for promoting and fostering innovation and preparing the workforce, with the aim of developing and improving the scientific and critical thinking skills needed for highly capable students. For An (2020), STEAM integration in the mathematics methods courses engaged students in four steps of the inquiry process: connection, collaboration, communication, and evaluation. Silvestri et al. (2025) confirm that a transdisciplinary STEM task designed around these same phases keeps mathematical ideas explicit while heightening students' sense of relevance and ownership. Similarly, El Bedewy et al. (2025) shows that embedding geometry in an architectural-modelling STEM sequence positions students as active designers, sustaining engagement and deepening conceptual mastery. The benefits of integrating a STEM education approach with PBL, especially in math and science, where students frequently exercise critical thinking and analytic thinking, align with this structured inquiry process (He, 2022). Hickman and Akadere (2017) argued that the STEM-PBL method helps students develop collaborative problem-solving skills, creating an inclusive and safe learning environment for them and preparing a 21st century workforce (Corlu et al., 2014).

Developing 21st Century Skills through Project-Based Learning

Research shows that PBL teaching method encourages development of 21st century skills such as critical thinking, problem-solving skills, communication, digital literacy skills, and teamwork (Bell, 2010; Fami et al., 2023; Haleem et al., 2022; Halvorsen et al., 2012). Moreover, Gillard (2009), in his study, supports the concept that these skills may be taught and are neither born nor genetic. A recent study extends this evidence, demonstrating that STEM-oriented PBL significantly heightens students' personal, academic, and social competences across disciplines (García-Llamas et al., 2025). These authors describe PBL as a "competence accelerator," especially when projects are framed around authentic, cross disciplinary challenges. Furthermore, Evenddy et al. (2023) found that PBL creates an engaging learning environment where students actively collaborate and apply their knowledge to real-world problems, enhancing their ability to work in teams and manage projects efficiently. Studies have shown that PBL not only fosters essential skills but also increases student motivation and engagement (Blumenfeld et al., 1991).

Bender (2012) explains that when students confront real-world issues and problems that they find meaningful, they determine how to address them and then collaboratively work to create solutions through PBL. This method aligns well with constructivist theories of learning, which emphasize the importance of active involvement and personal relevance in the learning process (Piaget & Cook, 1952; Vygotsky & Cole, 1978).

According to Fami et al. (2023), integrating technology into PBL classrooms enhances students' digital literacy and prepares them for the needs of today's workforce. Students' perceptions of using PBL and technology in their classrooms appear to help them improve their intended prototype. In addition, the integration of technology in PBL enhances students' digital literacy and prepares them for the needs of today's workforce (Fami et al., 2023). Similarly, Haleem et al. (2022) show that students gain essential technological abilities that are important in the current digital era by utilizing digital tools for research, collaboration, and project presentation. This PBL component is especially significant since it gives students the tools they need to successfully navigate and use technology, which is a critical 21st century skill. On the other hand, Estapa and Nadolny (2015) argued that the use of technology can assist students in learning, exploring, and representing mathematics. Extending these findings beyond technical skills, Novalia et al. (2025) show that PBL functions as a catalyst for learning independence, with students becoming significantly more self-directed in setting objectives, managing time, and assessing their own progress.

Overall, the benefits of PBL extend beyond academic achievement; it contributes to students' overall development by developing important life skills and preparing them for future challenges. As educational paradigms evolve toward more student-centered methods, PBL emerges as an efficient approach for developing a well-rounded and capable generation of students.

CONTEXTUAL BACKGROUND

The USAID project, after school support for teens (ASSET) (http://asset-ks.org/), founded a makerspace lab at the local urban high school in Prishtina, Kosovo, where the study took place. The makerspace lab environment is equipped with state-of-the-art technology, such as an Arduino UNO, a 3D printer, a laser cutter, a CNC router, and various other devices. Ten students, participants in the high school ASSET program, the technician club, were selected to participate in the study. The participating students showed interest voluntarily based on their demonstrated interest in technology and engineering and their prior involvement in extracurricular STEM activities. The selection involved reviewing their academic performance, teacher recommendations, and willingness to engage in PBL.

With the support of the USAID ASSET program, the two authors (university professors) of this study developed the PBL teacher training program, which includes extensive PBL training for the schoolteachers, including one of the authors of this study. The goal of this teacher training program was to improve teachers' capacity to successfully incorporate STEM-PBL concepts into their lesson plans and use the makerspace lab. The study will show how the trained teacher facilitated inquiry-based learning activities in a makerspace environment and how that impacted students' mathematics achievement and skills development. **Table 1** shows the action plan and criteria during the four weeks of teaching and learning in a makerspace lab via the STEM-PBL teaching method.

The activities outlined above aimed to demonstrate the use of makerspace lab through engineering design process experiences, the use of various technologies, and mathematical knowledge to understand how students engage in hands-on activities and how these interactions impact the enhancement of their skills and their academic achievements in mathematics. The goal of these efforts is to establish a cohesive vision for supporting the academic success of students, with a particular focus on excelling in STEM courses.

The technician club members, consisting of four girls and six males, were motivated to collaborate during after-school hours on the STEM-PBL project "smart house." For four weeks, the high school teacher (author) has facilitated the technician club's project work. The teacher instructed the students on the principles of the STEM-PBL method and taught them how to utilize technical equipment and other resources to construct their

Table 1. Action plan and the four-week plan criteria for building the smart house

Week	Action
Week 1. Product building briefing	• Introduce students to the project requirements and tasks involved in creating a smart house for a two-person household. • Have students research similar model houses and come up with ideas for building their house in accordance with the project criteria. • Engage students in discussions about how to organize the house to maximize its functionality. • Instruct students to create and elaborate on their project action plan. • Communicate the criteria for model building: ○ Drafting a hypothetical scenario ○ The engineering design process leads to the creation of measured sketches. ○ Include geometric shapes in the construction process. ○ Use of modern materials and equipment such as 3D printers, laser cutters, and CNC routers. ○ Use recycled materials. ○ Ensure the durability of the models. ○ Include electronic parts. ○ Predict all measurements (length, surface, and volume). ○ This document serves to ensure the replication of the project and its accessibility. ○ Ensure a visually appealing and representative look. ○ Document the procedure with photographs and drawings.
Week 2. Architectural projects and optimum choice	• Students present their architectural projects and discuss their organizational scenarios. • Collaboratively choose the project that is both highly useful and cost-effective. • Conclude the architectural project and begin the process of creating models for the interior components. • Model the first mold prototype using Autodesk Fusion 360 (Tickoo, 2018) • Transfer the mold to "Cura" software for 3D printing preparation (Boozarjomehri, 2017). • Create detailed scenarios that describe the contents and functionality of the dwelling.
Week 3. Constructive building	• Construct the outside walls and windows of the building according to the architectural model. • Use the CNC router to precisely cut and shape windows and their individual components. • Produce three-dimensional geometric shapes for the interior using the 3D printer. • Work on the electronic parts, integrating sensors to enable digital functionality.
Week 4. Project completion and achievements	• Finalize the construction of the smart house. • Testing for functionality.

smart house. The participants were instructed to include geometric two- and three-dimensional shapes in the interior design of their houses. They were also encouraged to utilize advanced tools like 3D printers and Arduino electronic boards to integrate a range of sensors and servo motors. This would allow them to transform their house into a smart house. At the end of the project, students demonstrated the following learning outcomes from the math syllabus:

(1) problem-solving skills,

(2) mathematical communication,

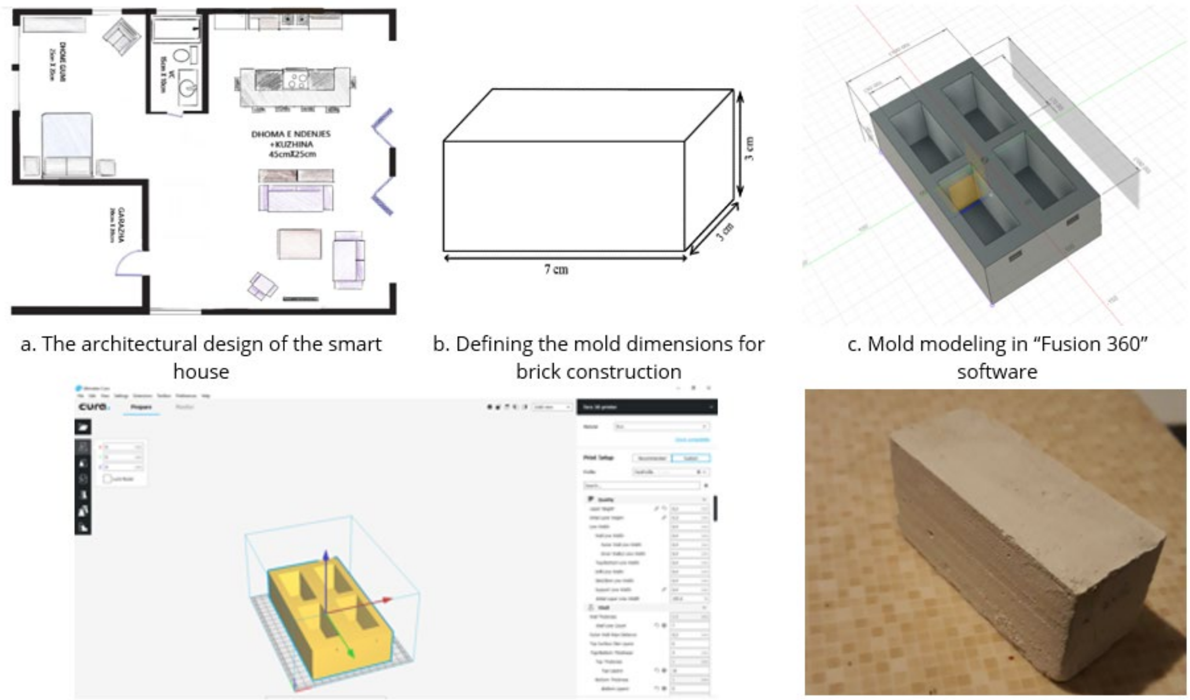
(3) connections with mathematics, and

(4) application of technologies in mathematics learning.

RESEARCH DESIGN

The study employs a qualitative research approach with a collaborative action research case study design, investigating the students' mathematics achievement and skill development through action research cycles of planning, action, observation, and reflection. Data were collected using the geometry concept understanding knowledge test and observation checklists while the students worked on their smart house project in the makerspace lab. The high school teacher and two university faculty members (trainers) collaborated to plan the study and create the observation checklist. Checklists were developed for three categories:

(1) measurements and calculations,



a. The architectural design of the smart house

b. Defining the mold dimensions for brick construction

c. Mold modeling in "Fusion 360" software

d. Transferring the mold to the Cura software for 3D printer modeling

e. Construction of the first brick

Figure 1. Makerspace activities, a to e. (Photos taken by the researchers in the makerspace)

(2) 3D shape modeling, and

(3) the use of technological equipment.

Additionally, checklists were used to identify skill development in the following categories:

(1) research skills,

(2) communication,

(3) teamwork throughout the process, and

(4) problem-solving skills added in the final two weeks.

At the start of every workday, one hour was dedicated to explaining geometrical concepts. This was done since it was noticed that students were struggling with conceptual understanding of some geometrical concepts as well as problem solving with geometrical concepts. Following the project's conclusion, a knowledge test on geometry concepts was conducted, consisting of five problems (Berani, 2012, pp. 131–135). Throughout the process, the authors of the paper served as critical friends for each other.

Using the STEM-PBL method showed to have an impact on actively engaging all students in the design and construction of the smart house. Students were more focused, and they were able to deeply understand the concepts of geometry. The following section provides extensive material that offers crucial insight into how students learn and the challenges of real-world problems that arise when using the STEM-PBL method.

Building the Smart House

In the first week of the project, students designed an architectural project with the relevant dimensions (sub-figure a in **Figure 1**). This phase involved planning and outlining the basic structure of the smart house according to the predefined criteria. In the second week, students began modeling the house as well as its internal components. They created a brick using a mold, which supposedly they would later use to construct the walls. Sub-figures a to e in **Figure 1** illustrate the progression of this modeling process, the creation of component elements for the smart house model, and the students' work.

However, in the third week, students determined that building the home model using bricks was both expensive and time-consuming. They proceeded to complete the construction of the outside walls and windows according to the updated architectural specifications. Sub-figures a to c in **Figure 2** depict the labor

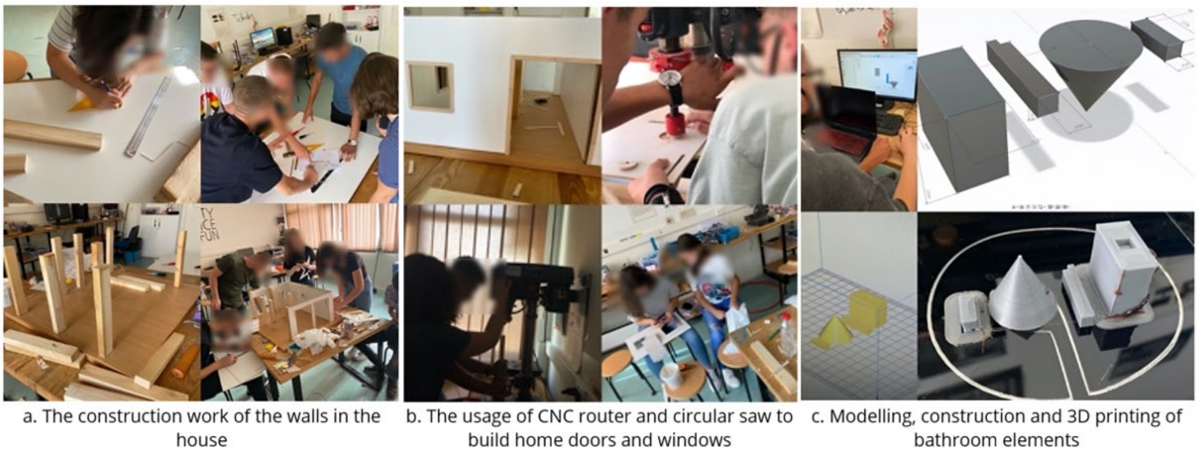


Figure 2. Makerspace activities, sub-figures a to c. (Photos taken by the researchers in the makerspace)

Figure 3. Makerspace activities, sub-figures a to d. (Photos taken by the researchers in the makerspace)

and organizational procedures that occur during this period. Students used a CNC router apparatus to cut windows, and circular saws to achieve finesse and accurate building details (sub-figure b in **Figure 2**). Sub-figure c in **Figure 2** illustrates how the 3D printer advanced the process of creating geometric 3D forms by completing the kitchen and bathroom components.

In the fourth week, students used recycled wood materials in their projects. Sub-figure a in **Figure 3** illustrates the first use of a laser cutter in this smart house design phase. Sub-figure b and sub-figure c in

Figure 3 display the final phase of the smart house project, encompassing interior design. The students used electronic components and integrated various sensors to enable digital operations within the smart house. Sub-figure d in **Figure 3** provides documentation of the elements of their work, using different sensors for digital home functionality.

Observation Checklist Results

The researchers used checklists to observe student's participation in practicing applying mathematics and developing skills during the project completion. For each item on the checklist, students received two points for an exceptional contribution to the measured skills, one point for a satisfactory contribution to the measured skills, and zero points for no contribution at all. **Table 2** and **Table 3** detail the percentages of skill development and math practiced over a four-week period.

Table 2. Percentage of skill development over four weeks

	Research skills	Communication	Teamwork	Problem-solving
Week 1	70%	75%	60%	-
Week 2	80%	75%	70%	-
Week 3	85%	80%	80%	85%
Week 4	90%	85%	85%	85%

Table 3. Percentage of students who practiced mathematics over a three week period

	Measurements and calculations	Modelling 3D shapes	Used of technology
Week 1	-	-	-
Week 2	75%	65%	40%
Week 3	85%	85%	75%
Week 4	90%	85%	90%

Most students demonstrated research skills during the first week of the project, with some demonstrating these skills at a satisfactory level and others at an excellent level. The study found that students' research skills improved consistently throughout the project, increasing from 70% in week 1 to 90% by week 4. Because they became more familiar with the project's goals and requirements, it appears that students' research skills improved as the project progressed. Communication skills also demonstrated consistent improvement. Starting at 75% in week 1, these skills improved to 85% by week 4. This shows that students were actively sharing their ideas and interacting with their peers throughout the smart house creation process. Their capacity to effectively communicate and collaborate contributed to successfully fulfilling all given tasks.

The first week revealed some negative aspects of teamwork. Some students tended to dominate talks by insisting on their ideas, while others kept silent and did not actively share their thoughts or proposals. To address these difficulties, the first reflection session emphasized the importance of listening to and evaluating each other's perspectives. Teamwork abilities increased significantly, from 60% in Week 1 to 85% in week 4. This improvement indicates students' increased ability to operate productively in groups. As students became more accustomed to working together on projects, their teamwork abilities improved, allowing them to complete tasks more efficiently. Students demonstrated good problem-solving skills from the start of week 3, sustaining an impressive 85% through week 4. This constancy implies that students could address and overcome obstacles that developed during the project. Their ability to efficiently address challenges was critical to navigating the project's complexities and achieving successful outcomes.

During the first week, we did not use the observation checklists to track mathematical concepts and activities, as the students claimed to lack understanding of geometric concepts. Therefore, we dedicated an hour at the start of every workday to explaining geometrical concepts. However, beginning with week 2, students began to make excellent progress in measurements and calculations. By week 4, the ability to employ mathematical measures and calculations had improved significantly, from 75% to 90%. This improvement implies that, with more practice, students will become more adept at applying mathematical concepts. Similarly, students' ability to model three-dimensional shapes improved significantly. Beginning at 65% in week 2, this skill level had increased to 85% by week 4.

This growth suggests that students are becoming more skilled at using mathematical concepts to create 3D models, indicating their rising proficiency in this field. In terms of technological use, there was a significant improvement throughout the project. Students have been hesitating at the start of the second week of work to use technological equipment because some of them hadn't used it before. By week 4, 90% of students were effectively using technology, up from only 40% in week 2. This significant development suggests that as the study progressed, students improved their ability to integrate technology into their mathematical skills.

Research demonstrates that the integration of a STEM-PBL method enhances students' practical mathematics and 21st century skills.

The Knowledge Test Results

The primary objective of the first task was to assess the students' comprehension of geometric concepts, including the relationships between side lengths, distance, area, and the application of the Pythagorean Theorem. The students were asked to solve the following task: *What is the area of the figure formed by 5 squares (as shown in fig.1) if the distance AB is 7 m? Describe the problem's solution step-by-step.* Overall, the students performed well on this task. Nine students provided the correct answer, explaining all steps of the solution, while one student gave a wrong answer because of incorrect calculations. **Figure 4** illustrates an exemplary solution provided by one of the students for the first task.

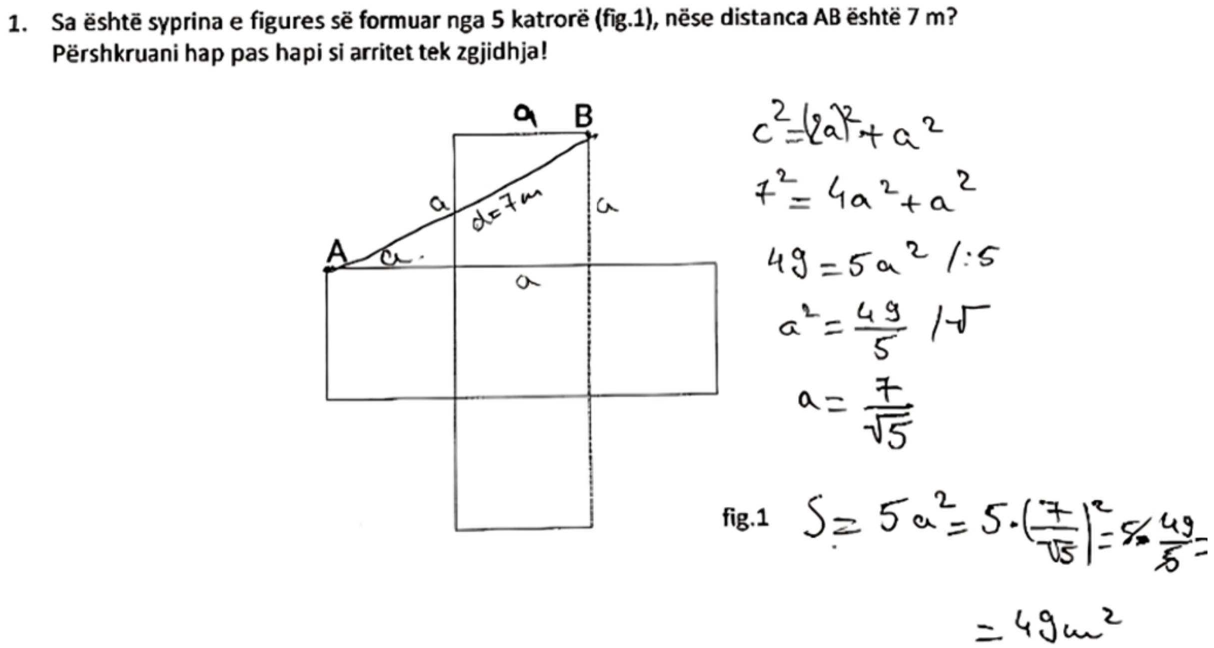


Figure 4. The students' solution of the first task. (Students' work collected by the authors)

The second task requested that the students solve the following problem: *The rectangle is placed so that its corners divide the length of the square into the ratio 1:2, i.e., a = 2b (as shown in fig.2). What is the area of the square that the rectangle covers?* The question was designed to test the students' ability to apply their understanding of side ratios to the area of a square and a rectangle. Regarding this question, two students offered no response, while eight students, in addition to the different models, solved the problem and achieved the correct result of the task. The reason for the poorer performance in solving the problem is due to the higher complexity needed to do the work. Unlike assignments that merely require the substitution of values into formulas, this one needed the integration of algebraic and geometrical knowledge. To find the area, students had to manipulate and grasp the side ratio and then apply this knowledge to geometric ideas. **Figure 5** displays one of the students' solution for the second task.

In the third task, all students successfully completed the calculation of the cone's volume, although there were differences in their work. The third task requested that the students solve the following problem: *Calculate the volume of a cone with a height of 5 cm and a base diameter of 7 cm. Draw the figure and explain step*

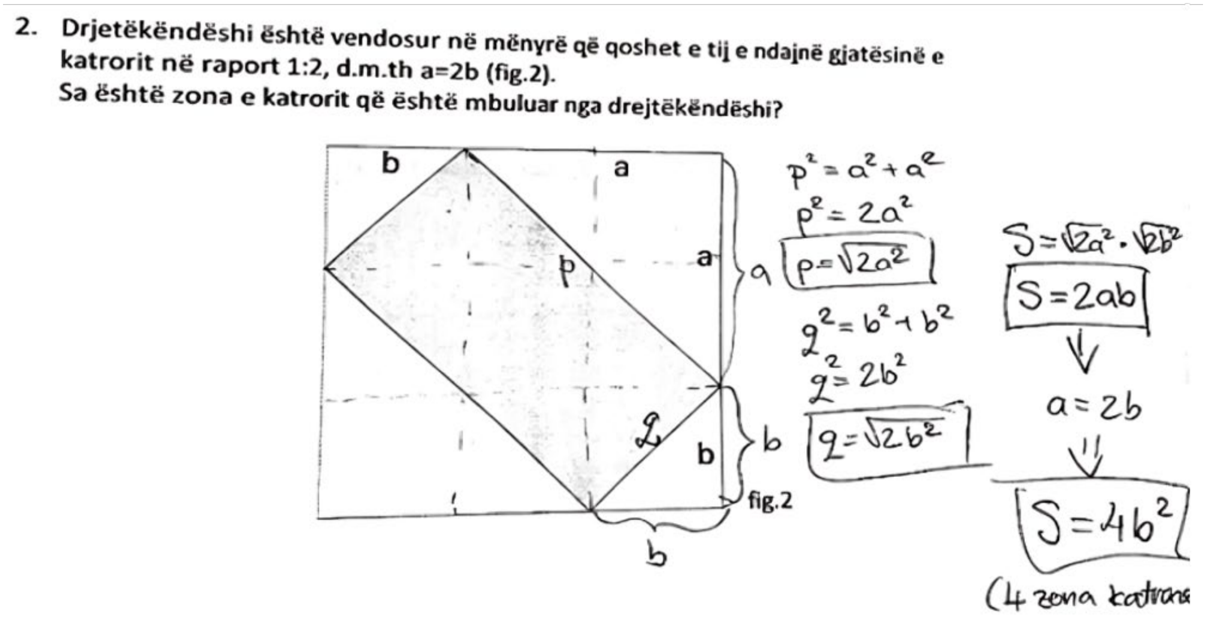


Figure 5. The students' solution to the second task. (Students' work collected by the authors)

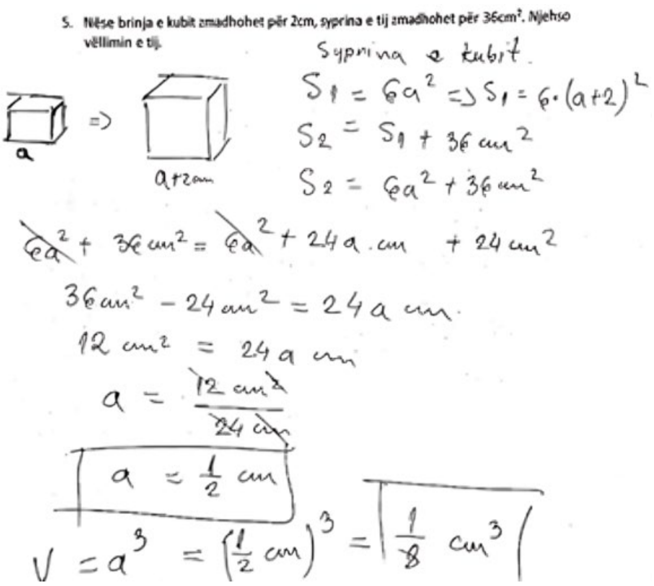


Figure 6. The students' solution to the fifth task. (Students' work collected by the authors)

by step how to solve the problem. In the fourth task, students faced difficulties grasping the concept of volume invariance. They were required to answer this request: *What will be the surface and volume of the cube formed by fusing cubes with sides 3 cm and 4 cm, respectively?* Most students attempted the task. Two students made calculation errors, resulting in incorrect answers. Eight students provided the correct results, but three of them did not use the correct measurement units. Only one student performed the calculations correctly, used the correct units and also commented on the concept of volume invariance. The last problem posed to students was: *If the side of the cube is enlarged by 2 cm, its surface area is enlarged by 36 cm^2. Calculate its volume*. The final test question asked students to demonstrate their understanding of the cube's surface's variability as its side increases by a specific number. Six students gave correct answers to the task; one student did not reach the result, while three others gave wrong answers. **Figure 6** presents one of the students' accurate solutions.

To further examine the students' performance, a one-sample t-test, shown in **Table 4**, was conducted for each task to compare the mean scores against a hypothesized mean of 1.5. The t-test determines if observed variations in student performance are statistically significant.

Table 4. One-sample t-test results for mathematical tasks

Task	t	df	Significance (2-tailed)	Mean difference	95% CI of the difference (lower)
Task 1	3.343	9	.009	.600	.19
Task 2	1.801	9	.105	.700	-.18
Task 3	7.856	9	.000	1.200	.85
Task 4	5.237	9	.001	.800	.45
Task 5	3.375	9	.008	.900	.30

Note. Test value = 1.5

Table 5. Descriptive statistics for overall test scores

Measure	N	Mean	Standard deviation	Standard error mean
KEST	10	11.70	1.767	0.559

Note. KEST represents the overall test scores for the sample

Table 6. One-sample t-test results for overall test scores

Measure	t	df	Significance (2-tailed)	Mean difference	95% CI of the difference (lower)
KTEST	3.042	9	.014	1.700	.44

Note. Test value = 10

For the overall test, the maximum possible score was 15 (as each of the five tasks could score up to 3 points). Students typically struggle with solving geometry problems, particularly when the tasks are non-routine. As a result, we assumed a hypothesized mean score of 10, reflecting the anticipated performance level given their difficulties with such problems. To determine if the difference between the observed mean and the hypothesized mean was statistically significant, we conducted a one-sample t-test. In our test, the average score was calculated to be 11.70 as shown in **Table 5**. The measured value is significantly higher than the expected value of 10. This shows that, despite the predicted obstacles, students outperformed expectations. The higher mean score suggests that students have a greater understanding of the geometric ideas and problem-solving skills involved in the test problems than previously thought. Effective teaching approaches like STEM-PBL or students' engagement with hands-on activities could be responsible for this progress.

The one-sample test with a test value of 10 as shown in **Table 6**, produced the following results: $t(9) = 3.042$ and $p = 0.014$. This shows a significant disparity between the observed and hypothesized mean scores. The mean difference was 1.70, with a 95% confidence interval (CI) of 0.44-2.96. This suggests that we can have 95% confidence that the true mean difference is within this range.

Furthermore, we found that Cohen's d was 0.96. This value indicates a large effect size, implying that the observed difference between the mean score of 11.70 and the expected mean of 10 is both statistically and practically significant. The large effect size indicates a significant and meaningful difference in student performance, emphasizing the importance of the educational intervention via STEM-PBL.

DISCUSSION AND CONCLUSION

The purpose of the study was to find out how the STEM-PBL method affected students' achievements in solving mathematical problems. The study also discussed the importance of this method in helping students improve their research skills, collaboration, teamwork, and problem-solving skills, and the use of technology to improve their learning. The study's statistics show a significant difference between the mean of the knowledge test and the hypothesized mean, as well as a large effect size, suggesting that the observed difference between the knowledge test mean score and the expected mean score is real. Additionally, the integration of a STEM-PBL method enhances students' practical mathematics and skills, including problem solving, research skills, communication, collaboration and linking their knowledge in real world applications. Our study's findings are supported by prior research indicating that the STEM-PBL method efficiently improves students' mathematics problem-solving skills (Halvorsen et al., 2012; Hickman & Akdere, 2017; Townley, 2020). The research conducted by Stohlmann et al. (2012) confirms that the use of the STEM-PBL method, which involves the application of mathematical concepts in real-world scenarios, promotes the development of a deep understanding of mathematical concepts and enhances students' ability to process abstract ideas.

Oldknow's (2010) argued that mathematics provides a great opportunity to embrace technology, use it, engage with it, and inspire them to discover more mathematical concepts, which supports the results of our study. Furthermore, he emphasizes that using technology in a math lesson improves student' achievement, influencing their motivation to learn math. Estapa and Nadolny (2015) have shown that technology usage, in addition to implementing conceptual knowledge in mathematics, has also impacted general achievements in other technical or conceptual fields. During the research's early stages, it was observed that many students were hesitant to use technology equipment. Fortunately, as the intervention progressed students were able to transform this hesitation into an excellent way of using the technology.

The examination of the students' observations checklists revealed that some students had developed their research, problem-solving, communication, and teamwork skills within a week of starting the STEM-PBL method of teaching and learning, while others only made progress towards completing the project. Thus, we can draw the same conclusion as Gillard (2009) who claimed that abilities are neither innate nor inherited, instead, they can be learned. Despite the short four-week duration of the research, the students expressed the experience as an innovative opportunity to prepare for college-level work, especially in engineering courses that demand a diverse set of skills for success (Kumar & Hsiao, 2007). Similar to the findings of Stohlmann et al. (2012) our findings show that integrated STEM education has the potential to motivate students to pursue careers in STEM subjects and can enhance their interest and understanding in mathematics and science.

Despite never having met before, the group of technicians comprising the study's student participants collaborated immediately due to their drive to complete an unfamiliar task. Apart from their dedication to promoting mathematical knowledge, they have demonstrated a strong drive to acquire technology-use abilities, particularly in the area of electronic device usage, which is essential for establishing a smart home. Similarly, Dacumos (2023) has shown that student participation in PBL demonstrates the development of fundamental abilities combined with scientific methods since students immerse themselves in contemporary challenges and problems to find answers.

The students faced challenges during the project implementation process, particularly when they had to make decisions about changing the architectural plan, such as altering the construction materials from brick to recycled wood. However, they addressed each challenge with research, collaboration, and effective communication, leading to successful outcomes. This experience enabled students to express and apply their ideas to realize real-world scenarios, highlighting the integration of STEM fields and other necessary skills. So, the students showed excellent communication and creativity in their efforts to complete the project. Yet, it remains a challenge to implement such projects in regular classrooms, especially if students and teachers lack STEM-PBL teaching training.

The study highlights the importance of teachers collaborating with local or supporting institutions, universities, participating in professional development, employing curriculum training, allocating dedicated teacher planning time, and fostering open communication to promote teachers' effectiveness. Schools must offer assistance and foster collaborations among instructors with diverse licensures and backgrounds (Stohlmann et al., 2012). Stohlmann et al. (2012) have shown how teachers employed several strategies to assist one another, such as fostering collaboration among math, science, and other teachers to optimize student learning outcomes. They discovered that a flexible teacher can effectively reinforce or skip concepts in the class, depending on the students' needs. For instance, science teachers thoroughly addressed the topic of simple machines in their courses, leading them to either omit it from their curriculum (Stohlmann et al., 2012) or revisit it to reinforce the concept, as demonstrated with the geometry concept in this study.

The study demonstrates that just memorizing materials and information without actively engaging with them and understanding their context, which are characteristics of the conventional educational approach, no longer adequately equips students with the essential knowledge and skills required to thrive in the modern world. It is imperative to integrate the STEM-PBL method into the educational process, as it enhances not only the acquisition of knowledge and information from many disciplines but also the development of essential life skills. The research suggests that revisions to the curriculum are necessary for students to excel academically in the numerous areas covered in the curriculum and to acquire 21st century skills. Reforming the curriculum and providing professional development for teachers are critical for advancing STEM education.

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