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The effectiveness of using educational robots in enhancing engineering mathematics skills among students in basic school

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ABSTRACT

Educational robots foster engaging, democratic, and collaborative learning environments, enhancing students' mathematical and engineering abilities by enabling them to interact, solve problems, assimilate information, and communicate effectively within the classroom. This study aims to examine the impact of educational robots on the development of engineering mathematics skills. The study uses a quantitative approach with a quasi-experimental design for a single pre- and post-test group. The sample consisted of 40 fifth grade students who initially studied geometry using traditional methods, followed by studying the same content using the educational robot. The study found that robot-based education significantly improved engineering mathematics skills. It was concluded that using educational robotics as a tool for teaching mathematics improved computational thinking, engineering mathematics, motivation, creativity, cooperation, and teamwork. It is possible to argue that the study's results corroborate relevant research showing how educational robots raise students' academic performance and improve their critical thinking. These results lend credence to the idea that educational robots improve learning beyond traditional approaches by actively involving students, giving subjects greater concreteness, and capturing their interest and attention. The study recommends the creation of new mathematical activities using educational robots across various mathematical contents and educational stages, further enhancing engineering mathematics among students.

Contribution/Originality: The study investigates the effectiveness of using educational robots in enhancing the mathematical skills needed by students to learn engineering content. Educational robots develop the learning process itself as well as the learners' abilities and competencies in addition to assisting in the effectiveness of the teaching–learning process.

1. INTRODUCTION

The desire to learn the skills needed in 21st century society has grown dramatically during the past few decades. To prepare students as future citizens in a society that is mostly focused on technology, proponents of this theory call for systematic educational reform that integrates technology with creative thinking, mathematical skills, and problem solving in educational settings (Papadakis, Vaiopoulou, Sifaki, Stamovlasis, & Kalogiannakis, 2021). Researchers and practitioners agree that implementing STEM (Science, Technology, Engineering, and Mathematics) education has been successful. The STEM learning process is effective because it demonstrates to students that they can apply their engineering mathematics skills, creativity, collaboration skills, and critical thinking skills. Therefore, STEM education encourages a link between instruction and learning in real-life situations (Evripidou et al., 2020). As a component of STEM education, educational robotics includes a wide variety of general knowledge and enables the translation of any discipline into a more complete educational environment. From preschool to university, and in special education contexts, educational robotics has drawn the attention of policymakers and researchers from all over the world. This is because it is a useful tool for developing students' mathematical, cognitive, emotional, and social skills (Talan, 2021).

As part of a creative and methodical approach to learning, the use of robotics in STEM education has been recommended (Darmawansah, Hwang, Chen, & Liang, 2023). Parallel to this, current research indicates that students' levels of interest, creativity, and ability for mathematical engineering are impacted by the use of robots in learning environments. Educational robots offer the chance to teach arithmetic, including engineering concepts and mathematical engineering abilities, as an essential component of education (Darmawansah et al., 2023). Robotic learning integration, according to Anwar, Bascou, Menekse, and Kardgar (2019), is crucial to assisting students who do not exhibit an early interest in math. The development of a variety of skills, including computational thinking, engineering mathematics, motivation and creativity, cooperation and teamwork, problem solving, and other higher thinking skills, can be sparked by a learner's interest (Evripidou et al., 2020). Robotics and tools have been used in various ways as a result of artificial intelligence, such as when creating educational activities (Hwang, Xie, Wah, & Gašević, 2020).

According to Pohjolainen, Nykänen, Venho, and Kangas (2018) results in mathematics are not entirely reliant on effective instruction, ample resources, or other external factors that affect learning. Attitudes, including orientations, intentions and motivations, are factors that have an impact on how a student performs. Activity on the learner's part is necessary to meet learning objectives, and since each student has unique attitudes and motivational elements, effective teaching should take these into consideration (Utomo & Syarifah, 2021).

Arbo and Ching (2022) claim that mathematics is frequently seen as an abstract concept to be explored. Many people hold the opinion that "it is okay to not enjoy math" because "not everyone can be a math genius." These ideas about the topic cause children to have little interest in and dread learning mathematics. Students who come into engineering mathematics skills classes with this preconceived concept are disengaged, uninspired, and demotivated to study the material. According to studies, students who perceived mathematics to be a challenging subject were far more likely to fail and leave school. Also, many students struggle mentally with math, which hurts their performance. The effects of having the incorrect impression present a significant obstacle to students in the majority of topics with numerical content. Many scientific and technological fields strongly rely on mathematics, even though the majority of students believe it to be unrelated to their personal and professional lives.

It is becoming increasingly obvious that the employment of educational robots has significant promise to optimize instruction within educational institutions as we better understand the individual characteristics of learners and the diversity of learning pathways. Additionally, according to Kálózi-Szabó, Mohai, and Cottini (2022) educational robots develop the learning process itself as well as the learners' abilities and competencies in addition to assisting in the effectiveness of the teaching–learning process. As a result, it serves both instructional and assistive purposes. We aim to investigate the effectiveness of using educational robots in enhancing engineering mathematics skills among basic school students.

1.1. Purpose and Study Questions

This study investigates the effectiveness of using educational robots to enhance the mathematical skills needed by basic school students to learn engineering content. To achieve this goal, the researchers try to answer the following questions:

1. Is there a significant difference between the non-random group pre-acquisition (PRE-ACEMS) and post-acquisition (POST-ACEMS) in their degree of engineering mathematics skills (EMS) in terms of using educational robots to teach the engineering content?
2. Is there a significant difference between the non-random group post-acquisition (POST-ACEMS) degree of engineering mathematics skills attributed to the nature of the skill?

2. THEORETICAL FRAMEWORK

2.1. Educational Robots in Teaching and Learning Mathematics

Educational programs began to use computer-assisted learning. Computer-assisted learning applications can include computer simulation, numerical analysis, computer-aided design, computer-aided manufacture, and educational robotics, which focus on the conception, creation, and implementation of robotic prototypes and specialized programs for pedagogical purposes (Wong & Shih, 2021).

Many procedures supporting multimedia technology with all of its components have been established as a result of the advancements in the field of information and communication technology (Bani Ahmad, Al-Nawaiseh , & Al-Nawaiseh, 2023).

Educational robotics has been growing exponentially in recent years. It has a major impact on learning (Di Lieto et al., 2017) and it is associated with the STEAM disciplines (Science, Technology, Engineering, Art, and Mathematics) for the development of skills and understanding in mathematical, physical, engineering, and related concepts across the various education sectors (Daniela & Lytras, 2018).

Since educational robotics adds diversity to the classroom and keep students engaged and motivated, its integration and use in the teaching and learning process at preschool, primary, and secondary levels can be beneficial and a turning point in the evolution of the educational process (Lopez-Caudana, Ramírez-Montoya, Martínez-Pérez, & Rodríguez-Abitia, 2020). In addition, it can be used as a tool to enhance knowledge building and enhance learners' skills in several aspects, such as creativity, communication, collaboration, critical thinking, teamwork, problem solving, and computational thinking (Negrini et al., 2023).

It is normal for students to have difficulties with a variety of learning materials. It is impossible to avoid problems in this aspect, especially when working with math (Alsmadi, Tabieh, Alsaifi, & Al-Nawaiseh, 2023). Mathematics learning environments require a range of methods, techniques, and strategies that support the acquisition of analytical and constructive processes. One of the most comprehensive methods that have proven effective in developing learners' mathematical skills is the active learning style, where the teacher seeks to enhance the students' participation as a consumer of knowledge and plans continuous stimulation activity so that the students individually or collectively perform higher-level actions, from analyzing and synthesizing interpretation to inference and evaluation (Pei & Zhou, 2023). In the literature, there is a great interest in educational robots as a technology that can be relied upon to enhance the educational process and offers significant benefits in learning and teaching (Fanchamps, Slangen, Hennissen, & Specht, 2021). Many studies have demonstrated the ability of educational robotics to allow students to explore, create and implement knowledge to deal with real problems and enhance learning outcomes (Ching et al., 2019). Educational robotics also improves critical and creative thinking, collaboration skills, and team spirit (Noh & Lee, 2020) and it is considered the most appropriate tool to support STEM education through activities using robots to apply their knowledge and skills (Durak & Saritepeci, 2018).

The use of robots and programming in teaching mathematics has received a lot of attention from researchers; one of the most popular applications is Papert's Logo, which has been applied in classrooms for more than 50 years, where students programmed a robotic turtle to turn and move, and a pen attached to it created geometric shapes. This application demonstrated that educational robotics is a useful tool for externalizing a learner's thoughts and making mathematical concepts easier (Green, 2020). The uses of robotic device applications in the field of education are characterized into four main areas (Scaradozzi, Screpanti, & Cesaretti, 2019):

1. *Assistive robots*: These help to overcome physical disabilities that limit learners from practicing educational activities.

2. *Social robots*: These can be considered as teachers or companions for students, occupying their interests and transforming lessons into interactive and connected learning environments.

3. *Socially assistive robots*: These help students to reduce social handicaps and assist users through social interaction rather than physical interaction.

4. *Educational robots*: These help students to develop many competencies related to technology and different sciences.

Recently, schools have begun to employ the use of robots in the educational process to improve the level and quality of the educational process and the learning outcomes by employing a new methodology to teach science, technology, engineering, and mathematics subjects, and to increase knowledge and competitiveness in scientific and technological fields. As an example, schools in Europe had a successful experience in this field, where high school students developed a Robot for Engineering (R4G) to teach mathematics and geometry to younger students (Cantarini, 2021). In Italy, robotics was introduced as a subject in primary school, and themes such as the Internet of things were included in the curriculum (Valzano, Vergine, Cesaretti, Screpanti, & Scaradozzi, 2021).

This research believes that the usage of robotics applications benefits the educational process since it allows students to utilize robots not only as platforms to learn robotics but also to assist them in understanding scientific subjects while they are learning.

2.2. Engineering Mathematics Skills (EMS) and Geometry

Engineering mathematics skills (EMS) refers to the proficiency and aptitude required by engineers to effectively apply mathematical principles and techniques in various engineering disciplines. These skills play a crucial role in problem solving, modeling, analysis, and design processes within engineering fields. Learning geometry by basic stage students requires a set of fundamental mathematical skills that serve as a foundation for understanding and applying geometric principles. EMS enables students to analyze shapes, angles and spatial relationships, and solve geometric problems effectively. Table 1 shows the EMS required to learn geometry content for students in the basic stage, according to Minda, Gillich, Chioncel, and IosifPraisach (2015).

Table 1. Engineering mathematics skills (EMS).

Code	Skills
A	Understanding counting, addition, subtraction, multiplication, and division
B	Critical and analytical thinking
C	Applying algebraic concepts to solve geometric problems
D	Understanding spatial relationships and geometric transformations (Translation, rotation, reflection, scaling)
E	Reading and comprehending geometric drawings and diagrams
F	Solving geometric equations to find unknown values
G	Using appropriate tools for measurement (Ruler, measuring tape, and protractor)
H	Ability to represent geometric shapes using equations
I	Understanding and interpreting visual data and graphs related to geometry
J	Measurement skills for measuring dimensions, distances, angles, areas, and volumes
K	Interaction and communication in solving geometric problems
L	Spatial visualization and analysis of shapes and objects
M	Applying geometric transformations to modify and manipulate shapes and objects
N	Applying mathematical skills to real-life geometric problems
O	Developing problem-solving skills in geometry through training and practical application
ACEMS	Enhancing engineering mathematics skills

2.3. The Link Between Geometry Outcomes and EMS

In Table 2, the learning outcomes of geometry at the basic stage are shown (Ashworth & Lee, 2023) along with the engineering mathematics necessary to achieve them.

Table 2. Geometry outcomes of basic stage linked with EMS.

Domain	Outcome	EMS	Percentage
Measurement data	Understand the concept of 2-D and 3-D shapes: Triangles, quadrilaterals, polygons, prisms, pyramids, cylinder, cone, and sphere	B, E, G, I, K, L, M, O	60%
	Understand the relationship between volume and the operations of multiplication and addition	A, C, F, H, K, O	40%
Geometry	Classify (Two- and three-) dimensional figures into categories based on their properties	B, C, D, J, K, M, N, O	53%

2.4. Learning Geometry Through Educational Robots

Learning geometry through educational robots offers a dynamic and engaging approach to teaching geometric concepts. Educational robots serve as interactive tools that foster active participation, problem-solving abilities, and spatial reasoning skills in students while exploring geometry. Figure 1 illustrates the conceptual framework of the study process that used educational robotics to design geometry-learning activities.

Learning activities in geometry using educational robots can be designed to offer engaging and interactive experiences for students. These activities not only help students understand geometric concepts better but also foster critical thinking, problem-solving, and teamwork skills. Figures 1 and 2 illustrate how educational robots are used in the classroom to teach geometry lessons.

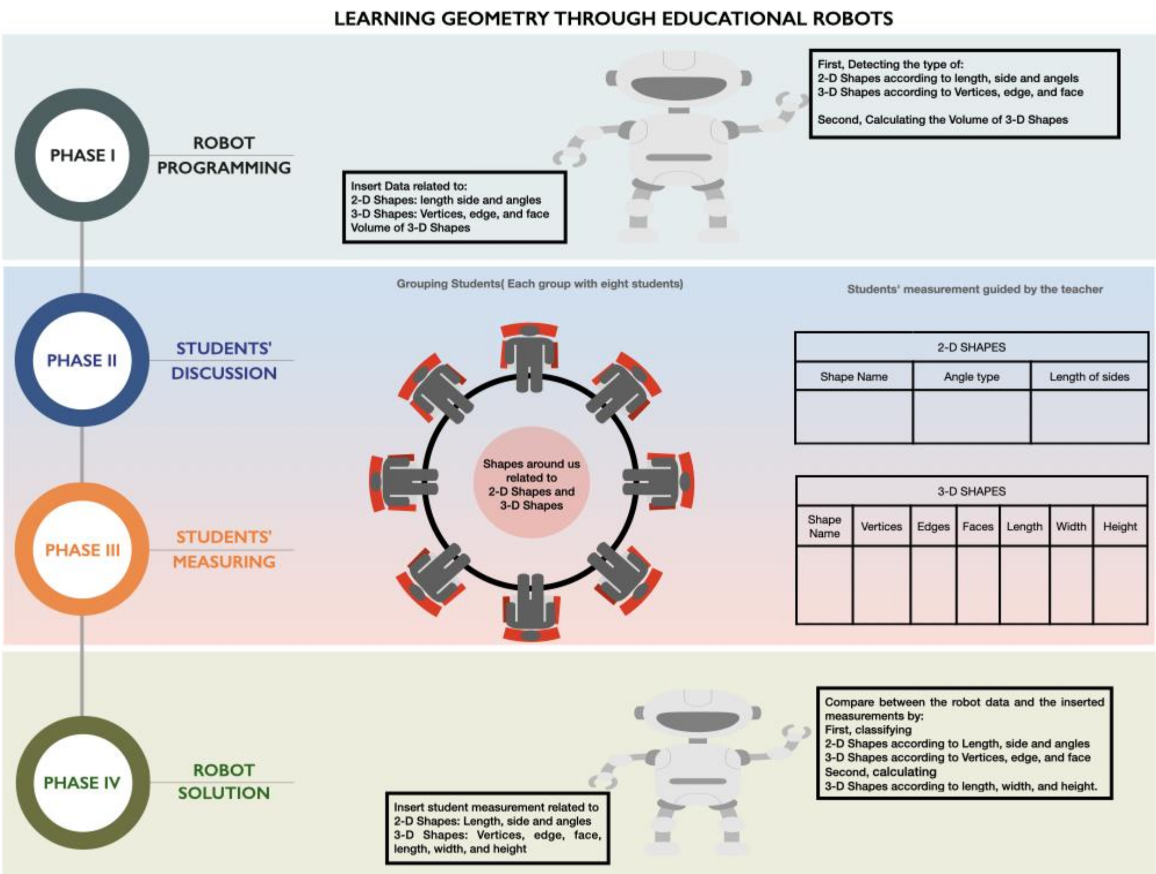


Figure 1. Learning geometry through educational robots.

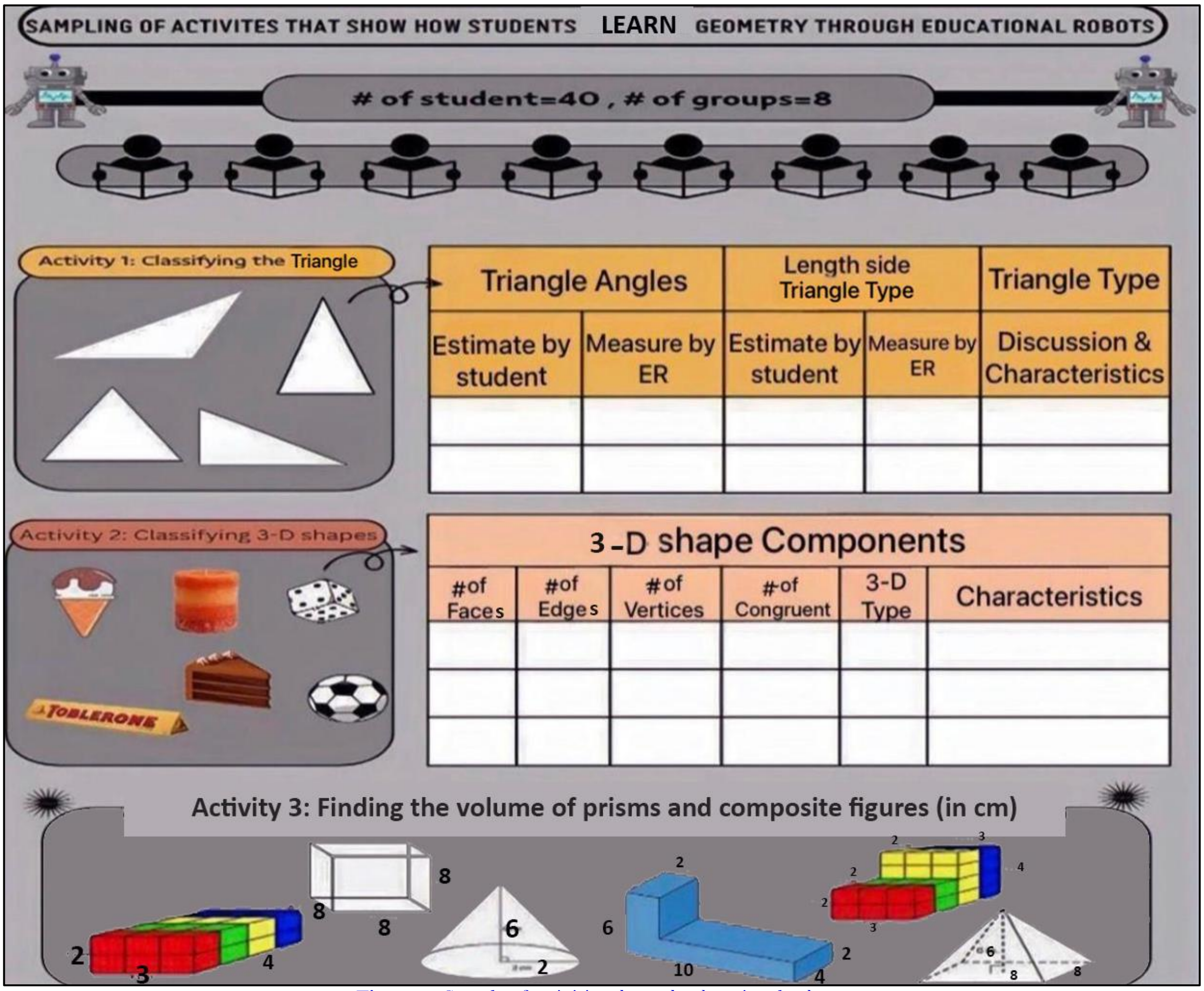


Figure 2. Sample of activities through educational robots.

3. LITERATURE REVIEW

Lamptey et al. (2021) investigated the impact of adopting robotics programs to foster interest in science, technology, engineering, and mathematics (STEM) among children with disabilities. The sample consisted of 57 children, and the results revealed that children with disabilities are more likely to learn from robotics programs, engage in the learning process, and show increased interest, attention, and motivation.

In addition, Isabelle, Andrade, and Livia (2019) investigated the effect of computational thinking and robotics on learning mathematics. The findings showed that using robotics in the classroom can enhance mathematical learning, stimulate computational thinking development and improve students' mathematical engineering skills.

Zhang, Luo, Zhu, and Yin (2021) conducted a systematic review to assess the existing studies in improving K–12 students' computational thinking and STEM attitudes. The study also advised educators about the influence of educational robots on STEM attitudes, improving the persistence of their learning effects, and the need for them to further investigate appropriate application models. The results demonstrated that educational robots had a significant impact on short-term instruction.

Tzagkaraki, Papadakis, and Kalogiannakis (2021) investigated the usage of educational robotics in elementary classrooms. The purpose of the study was to look into the usage of robotics, particularly the advantages it offers to students, the challenges it presents, and its place in the curriculum. The results show that educational robots are a novel and beneficial tool. It enhances creativity, teamwork, problem solving, computational thinking, critical thinking, and algorithmic thinking. The study also discovered that obstacles related to educational robotics can be attributed to either a lack of technology advancements or to instructors' deficiencies in critical knowledge or preparation for the successful integration of educational robots into primary school curricula.

Leoste and Heidmets (2019) studied the impact of educational robots as learning tools in mathematics learning, and the research clarified how educational robots can be used as learning tools in mathematics lessons and what the teachers' and students' attitudes are toward educational robots. The study showed a positive impact of using educational robotics as learning tools and there was also a positive attitude toward the use of the technology.

Most studies support the premise that educational robots are more successful than traditional approaches for supporting learning because they engage students in the learning process.

Many fields have benefited greatly from the advantages offered by robots. And since education presents a wide range of challenges, robots can help avoid them as they provide a unique educational experience with useful solutions to learners' needs, as pointed out by Caballero-Gonzalez, Muñoz-Repiso, and García-Holgado (2019) who stated that "the technological advance that is currently evident in the different social contexts is contributing to consolidate educational processes that allow the strengthening of technological and social skills in students." In their research, they studied the learning of computational thinking and social skills development in young children through problem-solving using educational robotics. The results show a significant improvement in the students in terms of their computational thinking and social skills.

3.1. Participants

A total of 40 fifth-grade students from international schools with artificial intelligence labs participated in this study. Purposive sampling was used to select the study sample. This type of sampling was used due to the logistics required to conduct the study effectively, the compatibility between the educational robot and the nature of the students and ensuring the students' interaction with the study tools and methodology.

4. METHODOLOGY

A quasi-experimental design was used, with pre- and post-observations of one group of students. The pre-observation was conducted to determine the degree to which the students possessed engineering mathematics skills. Following that, the students were taught the engineering content from a mathematics book within the specific study unit using the educational robot. After the teaching process, a post-observation was conducted to remeasure students' engineering mathematics skills and identify any differences between the two observations. Figure 3 shows the study design.

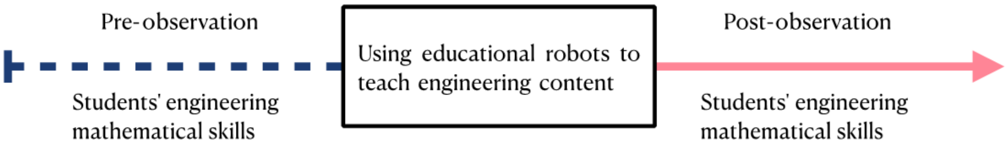


Figure 3. One group of pre–post observations design.

4.1. Data Collection Method

The data was collected by teachers observing the degree to which students possessed engineering mathematics skills. The teacher observed both students' cooperative and individual performances in five mathematical activities that covered the topics taught in the unit on geometry. Then, the overall mean of their proficiency in these skills was calculated twice: once while students were performing the five tasks in the traditional way, and a second time while they were using educational robots to complete the same tasks.

An observation card was developed by reviewing the literature and previous studies. The final form of the instrument consisted of fifteen mathematical skills needed for basic-level students to learn the geometric content in their textbooks. The instrument used a 3-point Likert scale (3 = proficient, 2 = trainee, 1 = beginner).

Content validity was used by presenting it to a group of mathematics education experts whose feedback and recommendations were taken into consideration. The constructive validity of the instrument was verified by calculating the correlation coefficient between each skill and overall performance. Table 3 shows the correlation coefficients of the overall performance.

Table 3. The constructive validity of the observation card.

#	Skills	Correlation coefficient	Significance level
1	Understanding counting, addition, subtraction, multiplication, and division	0.797	0.00
2	Critical and analytical thinking	0.878	0.00
3	Applying algebraic concepts to solve geometric problems	0.679	0.01
4	Understanding spatial relationships and geometric transformations (Translation, rotation, reflection, scaling)	0.797	0.00
5	Reading and comprehending geometric drawings and diagrams	0.790	0.00
6	Solving geometric equations to find unknown values	0.848	0.00
7	Using appropriate tools for measurement (Ruler, measuring tape, protractor)	0.785	0.00
8	Ability to represent geometric shapes using equations	0.867	0.00
9	Understanding and interpreting visual data and graphs related to geometry	0.928	0.00
10	Measurement skills for measuring dimensions, distances, angles, areas, and volumes	0.868	0.00
11	Interaction and communication in solving geometric problems	0.797	0.00
12	Spatial visualization and analysis of shapes and objects	0.878	0.00
13	Applying geometric transformations to modify and manipulate shapes and objects	0.679	0.01
14	Applying mathematical skills to real-life geometric problems	0.797	0.00
15	Developing problem-solving skills in geometry through training and practical application	0.790	0.00

The results in Table 3 show that there is a high correlation coefficient and statistical significance at $\alpha = 0.05$. This demonstrates that the instrument has strong internal consistency and is suitable for use. The researchers verified the instrument reliability using Cronbach's alpha coefficient, which had a value of 0.98, confirming that the observation card can be used as the study instrument.

4.2. Data Analysis

The nonparametric Kolmogorov–Smirnov goodness-of-fit test was used to test the normality of the data, and Levene's nonparametric test was used to test the variance homogeneity hypothesis. A paired samples Wilcoxon test was used to determine whether there is a significant difference between the non-random group pre-acquisition (PRE-ACEMS) and post-acquisition (POST-ACEMS) engineering mathematics skills in terms of teaching engineering content using educational robots. To examine the significant differences in the post-acquisition (POST-ACEMS) engineering mathematics skills, Friedman's Two-Way Analysis of Variance by Ranks was used. All statistical analyses in the study were conducted with the SPSS statistical package. The significance level was set at 0.05.

5. RESULTS

This study aimed to investigate the effectiveness of using educational robots in enhancing the mathematical skills needed by basic-level students to learn engineering content. The results of this study are outlined below.

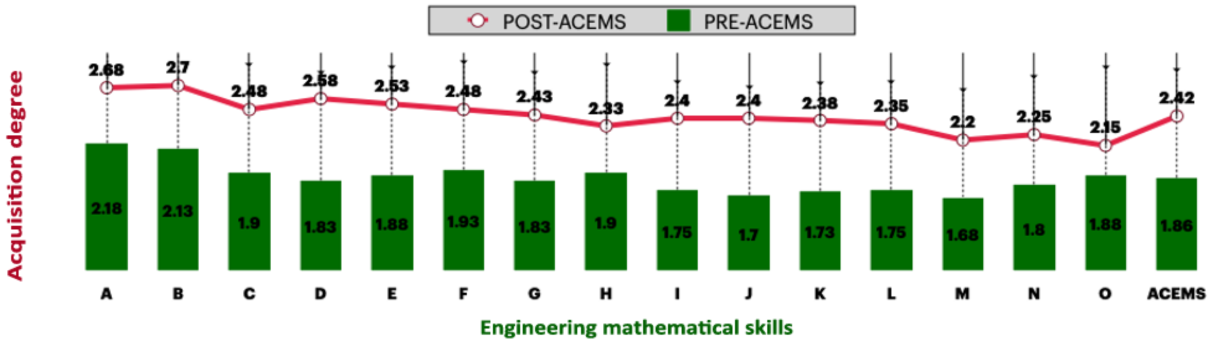
5.1. Normality and Homogeneity of the Distribution

Kolmogorov–Smirnov and Levene's tests were used to check the distribution's normality and homogeneity. Table 4 presents the results of the Kolmogorov–Smirnov goodness-of-fit and homogeneity tests from the pre- and post-observation data of the student group.

Table 4. Kolmogorov–Smirnov and homogeneity test results on the pre- and post-observation of the student group.

Observation		Normality test		Homogeneity test	
		Kolmogorov–Smirnov	p-value	Marginal homogeneity	p-value
Overall	Pre-observation	0.255	0.000	-4.250	0.000
	Post-observation	0.206	0.000		

Table 4 shows that the pre- and post-observations obtained by the study group revealed a non-normal distribution ($p \leq 0.05$). Non-homogeneity of variances in the pre- and post-observations of the study group was also found. Overall, the results of the Kolmogorov–Smirnov goodness-of-fit and Levene's tests indicate that the data can be analyzed using non-parametric tests.



Code	Engineering mathematical skills
A	Understanding counting, addition, subtraction, multiplication, and division
B	Critical and analytical thinking
C	Applying algebraic concepts to solve geometric problems
D	Understanding spatial relationships and geometric transformations (Translation,rotation, reflection, scaling)
E	Reading and comprehending geometric drawings and diagrams
F	Solving geometric equations to find unknown values
G	Using appropriate tools for measurement (Ruler,measuring tape, protractor)
H	Ability to represent geometric shapes using equations
I	Understanding and interpreting visual data and graphs related to geometry
J	Measurement skills for measuring dimensions, distances, angles, areas, and volumes
K	Interaction and communication in solving geometric problems
L	Spatial visualization and analysis of shapes and objects
M	Applying geometric transformations to modify and manipulate shapes and objects
N	Applying mathematical skills to real-life geometric problems
O	Developing problem-solving skills in geometry through training and practical application
ACEMS	The acquisition of engineering mathematical skills

Figure 4. PRE-ACEMS and POST-ACEMS of the student group.

5.2. The Effectiveness of Using Educational Robots to Enhance the Engineering Mathematics Skills among Basic-Level Students

Figure 4 and Table 5 show the paired samples' Wilcoxon test results of the significant difference between the non-random group's pre-acquisition (PRE-ACEMS) and post-acquisition (POST-ACEMS) degrees of engineering mathematics skills in terms of using educational robots to teach engineering content in a math book.

Figure 4 demonstrates the differences between the PRE-ACEMS and POST-ACEMS of the student group. It shows that the average acquisition degree of engineering mathematics skills after learning using the educational robot ($\bar{X}_{Post} = 2.42$) is higher than the average acquisition degree before learning using the educational robot ($\bar{X}_{Pre} =$

1.86). Additionally, the figure indicates that the means of the POST-ACEMS ranged from $\bar{X}_{Post} \in [2.15 - 2.70]$. "Developing problem-solving skills in geometry through training and practical application" achieved the lowest POST-ACEMS, while "critical and analytical thinking" had the highest POST-ACEMS.

The mean acquisition degree of the students before learning using the educational robot ranged from $\bar{X}_{Pre} \in [1.68 - 2.18]$. "Applying geometric transformations to modify and manipulate shapes and objects" achieved the lowest PRE-ACEMS, while "understanding counting, addition, subtraction, multiplication, and division" attained the highest PRE-ACEMS.

The figures also indicate that "understanding counting, addition, subtraction, multiplication, and division" and "critical and analytical thinking" are the two skills in which students achieved the highest levels of both PRE-ACEMS and POST-ACEMS, with pre-acquisition degrees of $\bar{X}_{APre,BPre} = 2.18, 2.13$ and post-acquisition degrees of $\bar{X}_{APost,BPost} = 2.68, 2.70$, respectively.

Table 5. Paired samples Wilcoxon test results on the PRE-ACEMS and POST-ACEMS of the student group.

Code	Engineering mathematics skills	Observation	n	$\bar{X}$	SD	Z	p-value
A	Understanding counting, addition, subtraction, multiplication, and division	PRE-ACEMS	40	2.18	0.78	-2.84	0.004
		POST-ACEMS	40	2.68	0.53		
B	Critical and analytical thinking	PRE-ACEMS	40	2.13	0.79	-3.10	0.002
		POST-ACEMS	40	2.70	0.56		
C	Applying algebraic concepts to solve geometric problems	PRE-ACEMS	40	1.90	0.78	-2.99	0.003
		POST-ACEMS	40	2.48	0.68		
D	Understanding spatial relationships and geometric transformations (Translation, rotation, reflection, scaling)	PRE-ACEMS	40	1.83	0.75	-3.97	0.000
		POST-ACEMS	40	2.58	0.59		
E	Reading and comprehending geometric drawings and diagrams	PRE-ACEMS	40	1.88	0.76	-3.47	0.001
		POST-ACEMS	40	2.53	0.60		
F	Solving geometric equations to find unknown values	PRE-ACEMS	40	1.93	0.69	-2.56	0.010
		POST-ACEMS	40	2.48	0.68		
G	Using appropriate tools for measurement (Ruler, measuring tape, protractor)	PRE-ACEMS	40	1.83	0.68	-3.10	0.002
		POST-ACEMS	40	2.43	0.68		
H	Ability to represent geometric shapes using equations	PRE-ACEMS	40	1.90	0.67	-2.46	0.014
		POST-ACEMS	40	2.33	0.66		
I	Understanding and interpreting visual data and graphs related to geometry	PRE-ACEMS	40	1.75	0.74	-3.44	0.001
		POST-ACEMS	40	2.40	0.71		
J	Measurement skills for measuring dimensions, distances, angles, areas, and volumes	PRE-ACEMS	40	1.70	0.72	-3.57	0.000
		POST-ACEMS	40	2.40	0.81		
K	Interaction and communication in solving geometric problems	PRE-ACEMS	40	1.73	0.64	-3.79	0.000
		POST-ACEMS	40	2.38	0.77		
L	Spatial visualization and analysis of shapes and objects	PRE-ACEMS	40	1.75	0.67	-3.46	0.001
		POST-ACEMS	40	2.35	0.74		
M	Applying geometric transformations to modify and manipulate shapes and objects	PRE-ACEMS	40	1.68	0.73	-3.09	0.002
		POST-ACEMS	40	2.20	0.82		
N	Applying mathematical skills to real-life geometric problems	PRE-ACEMS	40	1.80	0.65	-2.54	0.011
		POST-ACEMS	40	2.25	0.74		
O	Developing problem-solving skills in geometry through training and practical application	PRE-ACEMS	40	1.88	0.69	-1.71	0.088
		POST-ACEMS	40	2.15	0.83		
Overall	The acquisition of engineering mathematics skills	PRE-ACEMS	40	1.86	0.40	-3.79	0.000
		POST-ACEMS	40	2.42	0.43		

From Table 5 it is evident that there are statistically significant differences between the PRE-ACEMS and POST-ACEMS, favoring the POST-ACEMS ($Z = -3.79, p < 0.05$). The means and standard deviations of the degree of acquisition of the PRE-ACEMS and POST-ACEMS are $\bar{X}_{Pre,Post} = 1.86, 2.42$; $SD_{Pre,Post} = 0.40, 0.43$, respectively.

The table also demonstrates statistically significant differences between the PRE-ACEMS and POST-ACEMS of all engineering mathematics skills, favoring the POST-ACEMS, except for "Developing problem-solving skills in geometry through training and practical application," which indicates that learning using the educational robot did not lead to an improvement in this particular skill ($Z = -1.71, p > 0.05$).

Moreover, the table shows that the effectiveness of using educational robots in enhancing engineering mathematics skills reached 93%. This is evidenced by 14 out of 15 skills, demonstrating statistically significant differences in acquisition degree attributed to learning using educational robots.

Table 6 and Figure 2 show the Friedman's Two-Way Analysis of Variance by Ranks test results of significant differences in the post-acquisition engineering mathematics skills.

Table 6. Friedman's two-way analysis of variance by ranks test results on the POST-ACEMS of the student group.

Null hypothesis	n	DF	Chi-square	p-value	Decision
The distributions of APOST, BPOST, CPOST, DPOST, EPOST, FPOST, GPOST, HPOST, IPOST, JPOST, KPOST, LPOST, MPOST, NPOST and OPOST are the same.	40	14	38.93	0.000	The null hypothesis is rejected

Table 6 shows that there are significant differences between the POST-ACEMS, attributed to the nature of the skills ($Chi - Square = 38.93, p < 0.05$). Furthermore, Table 7 and Figure 2 present the pairwise comparisons between the means of the POST-ACEMS to identify the skills with significant impact.

Table 7. Pairwise comparison results between the POST-ACEMS of the student group.

Pairwise comparison	Test statistic	Sig.	Pairwise comparison	Test statistic	Sig.	Pairwise comparison	Test statistic	Sig.
OPOST-MPOST	0.20	0.841	HPOST-EPOST	1.39	0.165	IPOST-JPOST	-0.18	0.861
OPOST-HPOST	0.58	0.565	HPOST-DPOST	1.86	0.063	IPOST-CPOST	0.61	0.540
OPOST-NPOST	0.61	0.540	HPOST-APOST	2.38	0.081	IPOST-FPOST	0.63	0.532
OPOST-LPOST	0.90	0.368	HPOST-BPOST	2.71	0.007	IPOST-EPOST	0.75	0.453
OPOST-KPOST	1.06	0.288	NPOST-LPOST	0.29	0.774	IPOST-DPOST	1.23	0.221
OPOST-IPOST	1.21	0.225	NPOST-KPOST	0.45	0.653	IPOST-APOST	1.74	0.082
OPOST-GPOST	1.31	0.189	NPOST-IPOST	0.60	0.549	IPOST-BPOST	2.08	0.083
OPOST-JPOST	1.39	0.165	NPOST-GPOST	0.70	0.484	GPOST-JPOST	-0.08	0.940
OPOST-CPOST	1.83	0.068	NPOST-JPOST	0.78	0.438	GPOST-CPOST	0.51	0.608
OPOST-FPOST	1.84	0.066	NPOST-CPOST	1.21	0.225	GPOST-FPOST	0.53	0.600
OPOST-EPOST	1.96	0.055	NPOST-FPOST	1.23	0.221	GPOST-EPOST	0.65	0.516
OPOST-DPOST	2.44	0.095	NPOST-EPOST	1.35	0.177	GPOST-DPOST	1.13	0.261
OPOST-APOST	2.95	0.003	NPOST-DPOST	1.83	0.068	GPOST-APOST	1.64	0.102
OPOST-BPOST	3.29	0.001	NPOST-APOST	2.34	0.091	GPOST-BPOST	1.98	0.084
MPOST-HPOST	0.38	0.708	NPOST-BPOST	2.68	0.007	JPOST-CPOST	0.44	0.662
MPOST-NPOST	-0.41	0.680	LPOST-KPOST	0.16	0.871	JPOST-FPOST	0.45	0.653
MPOST-LPOST	0.70	0.484	LPOST-IPOST	0.31	0.755	JPOST-EPOST	0.58	0.565

Pairwise comparison	Test statistic	Sig.	Pairwise comparison	Test statistic	Sig.	Pairwise comparison	Test statistic	Sig.
MPOST-KPOST	0.86	0.388	LPOST-GPOST	0.41	0.680	JPOST-DPOST	1.05	0.294
MPOST-IPOST	1.01	0.311	LPOST-JPOST	0.49	0.626	JPOST-APOST	1.56	0.118
MPOST-GPOST	1.11	0.266	LPOST-CPOST	0.93	0.355	JPOST-BPOST	1.90	0.057
MPOST-JPOST	1.19	0.235	LPOST-FPOST	0.94	0.349	CPOST-FPOST	-0.01	0.990
MPOST-CPOST	1.63	0.104	LPOST-EPOST	1.06	0.288	CPOST-EPOST	-0.14	0.891
MPOST-FPOST	1.64	0.102	LPOST-DPOST	1.54	0.124	CPOST-DPOST	-0.61	0.540
MPOST-EPOST	1.76	0.078	LPOST-APOST	2.05	0.050	CPOST-APOST	1.13	0.261
MPOST-DPOST	2.24	0.052	LPOST-BPOST	2.39	0.071	CPOST-BPOST	1.46	0.144
MPOST-APOST	2.75	0.006	KPOST-IPOST	0.15	0.881	FPOST-EPOST	0.13	0.901
MPOST-BPOST	3.09	0.002	KPOST-GPOST	0.25	0.803	FPOST-DPOST	0.60	0.549
HPOST-NPOST	-0.04	0.970	KPOST-JPOST	0.33	0.745	FPOST-APOST	1.11	0.266
HPOST-LPOST	-0.33	0.745	KPOST-CPOST	0.76	0.446	FPOST-BPOST	1.45	0.147
HPOST-KPOST	-0.49	0.626	KPOST-FPOST	0.78	0.438	EPOST-DPOST	0.48	0.635
HPOST-IPOST	-0.64	0.524	KPOST-EPOST	0.90	0.368	EPOST-APOST	0.99	0.323
HPOST-GPOST	0.74	0.461	KPOST-DPOST	1.38	0.169	EPOST-BPOST	1.33	0.185
HPOST-JPOST	-0.81	0.417	KPOST-APOST	1.89	0.059	DPOST-APOST	0.51	0.608
HPOST-CPOST	1.25	0.211	KPOST-BPOST	2.23	0.062	DPOST-BPOST	0.85	0.395
HPOST-FPOST	1.26	0.207	IPOST-GPOST	0.10	0.920	APOST-BPOST	-0.34	0.736

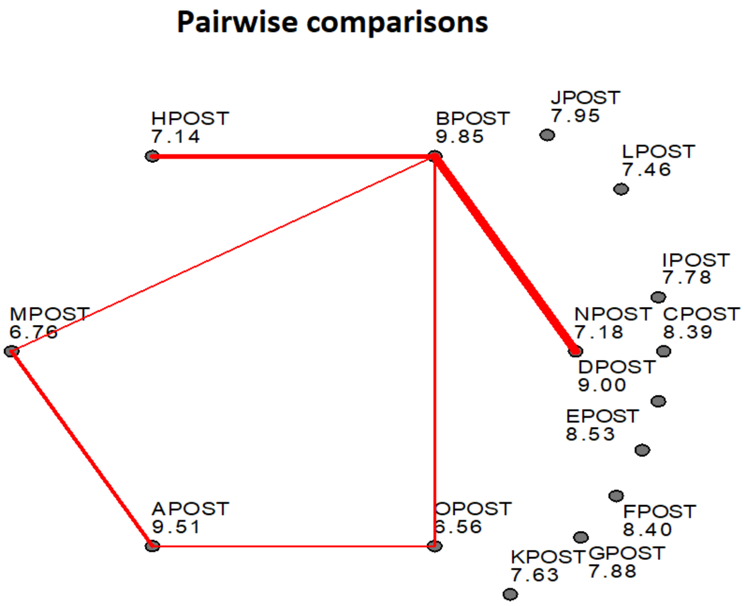


Figure 5. Significant pairwise comparisons of the POST-ACEMS of the student group.

From Table 7, it is evident that learning using the educational robot has significantly enhanced students' critical and analytical thinking skills. Additionally, the impact on their ability to represent geometric shapes using equations, apply geometric transformations to modify and manipulate shapes and objects, apply mathematical skills to real-life geometric problems, and develop problem-solving skills in geometry through training and practical application is lower than the impact on critical and analytical thinking ($Test_{B-HPost} = 2.71, Test_{B-MPost} = 3.09, Test_{B-NPost} = 2.68, Test_{B-OPost} = 3.29$; $p < 0.05$). In accordance with Figure 2, the mean ranks for these five skills reached $R_{BPost} = 9.85, MR_{HPost} = 7.14, MR_{MPost} = 6.76, MR_{NPost} = 7.18, MR_{OPost} = 6.56$.

Furthermore, learning using the educational robot has significantly enhanced students' skills in understanding counting, addition, subtraction, multiplication, and division. Moreover, it has shown an even greater improvement than the enhancement observed in applying geometric transformations to modify and manipulate shapes and objects, and developing problem-solving skills in geometry through training and practical application ($Test_{A-MPost} = 2.75, Test_{A-OPost} = 2.95, p < 0.05$). In accordance with Figure 2, the mean rank for the three skills reached $MR_{APost} = 9.51, MR_{MPost} = 6.76, MR_{OPost} = 6.56$.

Table 7 and Figure 5 demonstrate that the remaining pairwise comparisons between the means of the POST-ACEMS are not statistically significant.

6. DISCUSSION

The main objective of this study was to investigate the effectiveness of using educational robots in enhancing the mathematics skills needed by basic-level students to learn engineering content. It was discovered how well using educational robots can improve the mathematical and engineering skills of elementary school children. According to this study, the employment of educational robots in the classroom had a positive impact on students' engineering mathematics skills (Talan, 2021) and the results regarding the integration of educational robotics into math lessons corroborate previous studies. The data obtained shows how employing instructional robots can help students to strengthen their mathematical and engineering skills while also advancing the field of instructional robotics with a beneficial new technique. A number of studies have demonstrated the effectiveness of instructional robots in the classroom (Çınar & Tüzün, 2021; Kert, ErkoÇ, & Yeni, 2020; Ozer, 2019; Usengül & Bahçeci, 2020).

In this instance, it can be claimed that the study's findings are consistent with the literature and that the aforementioned application raises students' academic accomplishments. These findings support the claim that educational robots are more effective than conventional methods for facilitating learning because they engage students in the learning process, concretize the subjects, and spark their interest, attention, and motivation (Witherspoon, Schunn, Higashi, & Shoop, 2018). Additionally, students' dexterity improved, and the course was made more engaging by permitting the use of rich and readily available material, so the students were able to learn while having fun, which increased their learning (Lopez-Caudana et al., 2020; Negrini et al., 2023). However, other studies, such as Çakır, Korkmaz, İdil, and Erdoğmuş (2021) and Talan (2021) suggest that the engineering and mathematical skills of educational robots have not significantly improved, or have not significantly differed from other studies. Overall, the results of the study show a significant relationship between the students' engineering mathematics skills and demonstrate that learning with the educational robot greatly improved their skills in critical and analytical thinking, the ability to represent geometric shapes using equations, applying geometric transformations to modify and manipulate shapes and objects, applying mathematical skills to real-life geometric problems, developing problem-solving skills in geometry through training and practical application, and understanding counting, addition, subtraction, multiplication, and division.

The students' skills in understanding counting, addition, subtraction, multiplication, and division had the highest value. A skill comparison showed that "developing problem-solving skills in engineering through training and practical application" was of the least value since it depends on several other skills to be realized.

This study demonstrates how incorporating robotics into math instruction can assist students in developing a deeper knowledge of mathematical ideas and can be an effective means of removing obstacles and nurturing understanding. This result is consistent with Ching et al. (2019) who showed that educational robotics allows students to explore, create, and apply knowledge in dealing with real-world situations, hence improving learning outcomes.

This study has the potential to motivate teachers to implement cutting-edge instruction strategies that will make math more interesting, entertaining, and approachable for all students.

7. CONCLUSION

Since sophisticated educational robots have only been accessible since the 1980s, using robots as teaching aids in the classroom is a relatively new area of study. There are very few studies that investigate the use of educational robots as a teaching aid for mathematics (Lopez-Caudana et al., 2020; Talan, 2021). In most cases, computational thinking, engineering mathematics, motivation and creativity, cooperation and teamwork, and problem-solving are found to be benefits of educational robotics as a tool for teaching mathematics (Evripidou et al., 2020; Leoste & Heidmets, 2019). The results of the study shed light on the question of whether educational robotics can significantly improve students' mathematical skills compared to standard classroom instruction. The research was carried out utilizing EV3 Robotics and special lesson modules created in collaboration with math teachers. The findings of this study on the integration of instructional robotics into math lessons mostly corroborate the findings of earlier investigations. The information demonstrates how using instructional robots can help students develop their mathematical and engineering skills and advances the field of instructional robots with a useful new strategy.

8. RECOMMENDATIONS

Following the completion of this investigation, a set of recommendations is made in light of the findings. First, it is advised that math teachers enhance the way they instruct students and integrate the teaching of engineering mathematics abilities with the use of educational robots. The study also recommends enhancing engineering mathematics skills among students by designing new mathematical activities using educational robots through various mathematical content and for different stages of education.

The Ministry of Education should support teacher training to equip them with the most recent teaching methods and strategies. Additionally, it is suggested that. in order to fully understand the impact of this study, future research should be conducted on a larger group of people in different stages of education. The future of education depends on creating tools that are simple to use and appropriate for expediting the educational process for students; therefore, teachers also need to be aware of the most recent advancements in educational robots and technology.

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