The Effects of Educational Robotics on STEM Students' Engagement and Reflective Thinking

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***Abstract*— This Full-Length Research Paper deals with the effectiveness of training using educational robots on developing various skills for metacognitive thinking and engagement. Educational Robotics (ER) is a subject that aims to introduce children to robotics and programming through hands-on activities starting at a young age. There is evidence that ER plays a crucial role in enhancing students' academic achievement, cognitive abilities, and programming skills. Despite the growing interest in implementing ER to promote learning outcomes, there has been far too little focus on demonstrating ER effects on the development of certain types of thinking abilities (e.g. reflective thinking), and social skills that include engagement and its pedagogical implications. This study aims to evaluate the effects of ER on STEM students' engagement and reflective thinking. A sample of 24 middle school students (age range: 11–13 years) took part in an intensive ER-Lab for 6 sessions (3 weeks) by using open-source hardware and software kits through articulated robots and mobile robots. The research data in this study are drawn from two main sources on a five-point Likert scale: engagement questionnaire, and reflective thinking scale. The results of this investigation showed that students keep pleasure experience interacting and performing robotics activities. The results also showed a remarkable superiority of the students' reflective thinking skills on the dimensions (habitual action, understanding, reflection, and critical reflection). Students reflected their expectations and challenges after ER training with sets of recommendations accordingly. This study contributes to robotics' STEM education by expanding the scope of prior research to provide evidence of ER impact on 21st-century skills, particularly, reflective thinking skills. Based on the study's findings, we suggest developing robotic activities in different ER learning scenarios for a better understanding of the engagement processes. We recommend expanding the pedagogical possibilities of ER in improving extensive thinking skills, adaptation, and encouraging socialization and collaboration. This encourages exploring the feedback, reflection, and needs of the teachers and parents in terms of the impact of ER training on students thinking skills.**

Keywords—Robotics, Arduino, reflective thinking, middle school, STEM

INTRODUCTION

Educational robotics (ER) is a learning environment that inspires the participants to build and design robotics activities [1]. By constructing programmable robots, student groups engage in playful collaborative problem-solving activities. ER assists students in delving into the science of programming and acquiring new knowledge, allowing them to learn a wide range of topics in the fields of computer science and technology [2]. ER also aids in developing children's creativity and improving cognitive capacities, particularly in the areas of science, technology, engineering, and math (STEM) [3]. Furthermore, these robots assist children in learning variety of skills, including self-evaluation and self-reliance, as well as a great deal about programming and technology [4]. The application of ER gained in school inspires children and teenagers to pursue these disciplines further. This is certainly true in the case of improving students' ability and capabilities of programming languages to operate robots by simplifying them [5]. Thus, student's learning should be designed more engaging and entertaining [6].

In recent years, these activities have expanded significantly in elementary and secondary school classrooms, as well as in outreach events, aiming at attracting students to college programs in computer science and applied technology [7]. Despite the growing research interest and efforts in ER, it seems that enough attention has not been paid to important factors like reflective thinking skills and collaboration scripts, which are significant elements of the ER curricula [8]. The process of using ER, on the other hand, is related to the field of educational technology use. Ronsivalle and colleagues stated that the process of using the ER kits is a decision-making process based on the specifications of the instructional design, and the principles of its use are related to the learner's characteristics [9]. Moreover, students learn how to evaluate their performance and apply learner-centered tactics by seeing the outcomes of their activities right away [10]. Therefore, designing robotic activities is crucial for students to cultivate higher-order thinking in ER training.

Reflective thinking helps students to improve and develop their methods of work and encourages them to change their way of thinking and learning and makes them a human beings of quality in their thinking and opinions [11]. Therefore, many recommendations have emerged regarding the necessity of integrating reflective thinking in the ER curricula, as it works to enable students to reconsider every small or large task they perform during their design of the robot, by asking themselves questions, which makes them look with a critical eye to their methods of work, and ways of dealing with scientific content [12].

There has been an increased recognition in ER research that investigated its effectiveness generally on programming abilities [24]. On the other hand, there is a need to examine the effect of ER on reflective thinking skills when conducting robotic activities in education [28]. Moreover, prior research recommended enabling learners to reflect on the learning experiences and conducting further intervention to examine ER impact [24-26]. While the prior work focused on investigating the effects of robotics intervention on computational thinking skills, it is imperative to determine students' engagements and their reflective thinking. Meanwhile, more concerns should be shifted from robotic technology to pedagogical implications on the students themselves [31]. Taking inspiration from previous work on ER, and the potential of robotics training activities and their impact on thinking skills, this study aims to assess the effect of an intensive ER training on developing STEM students' reflective thinking skills and engagement. This study is exploratory and interpretative in nature. Thus, it will use the case study design to examine how integrating ER activities help in developing reflective thinking skills and student engagement, in addition to the student's ability to participate and interact enthusiastically during the training. The work presented here provides one of the valuable investigations into firstly, to what extent did the robotics training activities contribute to the students' engagement? And secondly, what is the effect of integrating ER activities on developing reflective thinking skills for middle school students? We involved 24 middle school STEAM students in our investigation with leveraging the Arduino kits and lab facilities in the associated school. Results showed that students enjoyed robotic activities with a high level of engagement and thus it extended to its impact on their understanding and critical reflection. Moreover, they faced some challenges in this training, which emphasize matters of consideration to design robotic activities.

Our work provides evidence to facilitate thinking skills and programming abilities delivered by robotic training. We also demonstrate remarks of students' reflections on the training, which shed the light on practical implications and pedagogical approaches in education. Therefore, this study contributes to robotics' STEM education and technology-enhanced learning by expanding the research investigation to address ER with 21st-century skills, particularly, the reflective thinking skills. The findings of this study encourage developing effective strategies and robotic activities in ER training to enhance student's participation and enjoyment. The remainder of this paper is organized as follows: Section II presents the related work to the research variables. Section III presents the method and materials used to conduct the research, followed by the evaluation and discussion in Section IV. Finally, Section V concludes the overall work done and recommends future research directions.

II. Related Work

Experimental studies in the last five years on ER are varied. They focused on investigating ER impacts on academic achievement, performance, specific types of thinking skills, and social skills. The following parts demonstrate the related variables of ER research discussed in this work (i.e. students performance, thinking skills, and engagement).

A. Students Performance

Motivated by the increased interest in ER, Evripidou and colleagues conducted a study and suggested new ways of thinking with focusing on the related concepts. Their study highlighted that ER is important for providing learners with multiple opportunities, for example, self-realization, and keeping the educational experience alive for a long time as the educational situation requires. In addition, encouraging students to self-learning as these smart technologies captivate them [13]. Moreover, Xefteris explored that students who are preoccupied with ER will have a strong interest to realize how and why some technologies work, so their desire to learn increased more than students who were imposed to study some subjects by the teacher. Their desire to understand and compete incited them to enjoy learning. As students design, build and program a self-propelled robot, they are exposed to advanced mathematical, scientific, and technical concepts [14].

B. Thinking skills

According to the findings of Angeli and Valanides' study, ER can help students to improve their computational and innovative thinking skills by encouraging problem-solving, decision-making, and teamwork while designing and programming, as well as developing leadership, social relations, and responsibility [15]. The robot's ability to assist students in achieving some thinking skills helped the integration between sciences such as mathematics, electronics, programming, and general sciences, which provides a comprehensive understanding of science, and providing them a feasible understanding of how to integrate cognitive, human, and scientific sciences [16]. Reflective thinking is one of the essential thinking skills among 21st-century skills that is defined as using the scientific method for decision making that helps to identify "an individual's strengths and weaknesses by allowing individuals to question values and beliefs, challenge assumptions, recognize biases, acknowledge fears, and find areas of improvement" [21]. A recent study pointed out a positive and moderate relationship between computational thinking, programming self-efficacy, and reflective thinking [31]. As Koca and Recep state, ER has a positive impact on the development of reflective thinking skill towards problem solving [34].

C. Students Engagement

ER helps students connect with real-life issues because most of the projects proposed in laboratories are based on real-life experiences and situations, which helps students develop engagement skills in using the robot in their everyday lives, as well as teachers develop skills and capabilities and upgrade them to effective teaching theories based on modern learning requirements [17].

Learners are motivated and passionate about learning when they discover and follow the feeling of cognitive inquiry that grows through time to cause a greater depth of purpose [18]. To reach the goal of educational innovation, new approaches must be developed, including robot capabilities and 21st-century skills like communication and planning. In addition to boosting their self-esteem, success in one area motivates them to take on new tasks in other areas. As a result, the use of ER learned in school encourages children and teenagers to continue studying their academic subjects [19].

III. Method

Since this study is exploratory and interpretative in nature, the experimental treatment was conducted and relied upon one group of middle school students, posttests were done as shown in Fig. 1.

A. Participants

The participants in this study were a sample of students at the Presidential school in Andijan city, Uzbekistan. A group of middle school students (N = 24) participated in this research (ages 11–13) and took part in 6-sessions (3 weeks) of intensive ER-Lab using open-source hardware and software kits. Participants were 5-8-grade students. Out of 24 participants, female students made up 6 (25%). 22 students did not have prior experience dealing with robotics. The robotics teacher has 4 years of experience in robotics and has a study background in computer science.

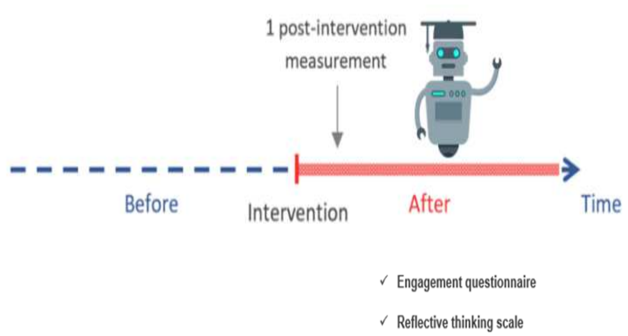

Fig. 1. Study design.

B. Materials

This study's research data come from two main sources: the engagement questionnaire and the reflective thinking measure, using a five-point Likert scale and featured various items in which students expressed their agreement on the scale.

According to the recommendation of [25], Arduino was used as an open-source computer hardware and software platform for creating digital devices and interactive artifacts with interaction and control features. Arduino boards are easy-to-use, able to read inputs - light on a sensor, a finger on a button, and turn it into an output - activating a motor, turning on an LED [29].

C. Procedures

Students are trained for participating in robotic activities in order to apply concepts acquired in their STEM classes, including computer science, technology and science. The included activities are: getting familiar with the parts of robotics and sensors; sketching the design of their machines and printing them out with 3D printers; writing codes for Arduino and creating artifacts for special occasions, as shown in Fig. 2.

Students learned how the Arduino platform works in terms of the hardware board, libraries, and Arduino IDE (integrated development environment) during the lessons. Moreover, they learned about shields during this intensive ER-Lab, which are little boards that plug into the main Arduino board to perform other activities like sensing light and heat. The ER-Lab also covers programming the Arduino with C code and utilizing the software to control external devices via the pins on the board. The ER training was performed during the first semester of the academic year 2021-2022 in an Uzbek STEAM school. The parents of students were informed and they gave consent about the participation of their children in the study.

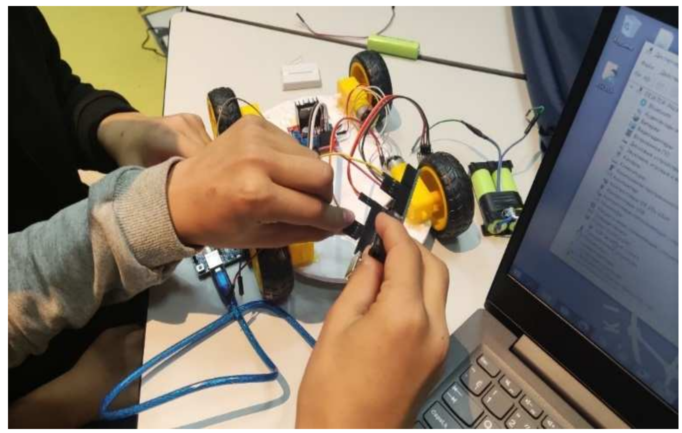

Fig. 2. Students participating in the ER training.

After the practical sessions, the teacher leads a discussion and reflection on what they have learned, and each team presents its own project, with pros and disadvantages discussed as the project is implemented. As shown in Fig. 3, each student is required to give a recommended vision of the project's future development.

Fig. 3. Post ER training discussion.

IV. Evaluation and Discussion

The evaluation method in this study opted for investigating students' participation and reflective thinking skills. An engagement questionnaire with eight statements was used to measure the keenness of students' engagement in the activities they perform, and the keenness to evaluate their performance on an ongoing basis [20]. We applied a reflective thinking scale to investigate the effect of ER on reflective thinking skills. The scale contained 16 statements to assess correct interpretation, analysis, evaluation, and inference, as well as to explain the information collected or communicated leading to purposeful, unbiased, and self-regulating judgment [21]. We also were interested to give the students the opportunity to share their experience after ER training and their comments are quoted in the following parts to support our evaluation.

A. Engagement

Students' roles in the educational process are evident in several ways. The students tried to break away from traditional thinking patterns and searched for innovative solutions to teachers' questions. Students are also keen to participate in training as well as their interaction with robots outside the classroom, as presented in Table I.

TABLE I. RESULTS OF ENGAGEMENT QUESTIONNAIRE (N=24)

NO	Engagement Questionnaire		
	Statement	***Mean***	***SD***
1	I had fun in this course.	4.9	0.1
2	I liked using the Arduino.	4.8	0.1
3	I'm glad I get to keep my robot.	5.0	0.0
4	I plan to keep playing with my robot at home.	4.9	0.1
5	After taking this course, I now have a better understanding of programming.	5.0	0.0
6	I'm now more interested in programming.	4.7	0.19
7	I now have a better understanding of robotics.	4.3	0.23
8	I'm now more interested in robotics.	4.6	0.21
Questionnaire Average		4.7	0.11

It is clear from the previous table that there is a noticeable added value in the participation rate and immersion in training among the students. The descriptive analysis was conducted to confirm this initial finding and SD reached an average of 0.11 with 4.7 in the total average mean. Thus, the result is statistically significant. Based on the foregoing empirical results of the current study, we found that ER practical training contributed to increasing students' ability to be innovative and not bound by traditional patterns and routines that might cause them to feel bored and distressed. Students liked the robotic training and found it interesting. Their comments emphasized that they like writing the codes, assembling robot parts, and running the robot after the training. Some of them commented:

"I would be happy to make a good robot for myself"

"It was fun making a robot"

Moreover, students have the ability to self-learning, precisely because they have searched for information, tried to understand, assimilate, etc. This finding is consistent with the finding of [22] that highlighted ER training encouraged cooperation between STEM students, and consolidated good relations between them, by giving them an opportunity to interact with each other in a positive way to accomplish a specific task. In addition, this training raised the level of awareness among students and helped to acquire experiences and skills that allow them to succeed in their lives. On the same note, increasing the self-confidence of each student, and this is what helps him/her later to succeed in various aspects of their life [23]. Some of their comments are mentioned below:

"I like to enter code because each code performs a separate function"

"They are modern and interesting"

Although they expressed their interest in this training, they referred to some challenges while the training. They found difficulties in writing the codes and performing some techniques with showing fear of programming. Few students indicated that the training consumes much time, especially since there are many practical activities involved.

B. Reflective Thinking

In this study, we used the scale designed by Kember and colleagues [21] to measure the effect of ER training on the reflective thinking among students. This scale has four dimensions of reflective thinking (habitual action, understanding, reflection, and critical reflection) to evaluate the thinking processes, taking all relevant facts arranged in a logical order in the computation in order to arrive at a solution to the problem, as described in Table II.

TABLE II. DESCRIPTIVE STATISTICS FOR THE MEANS OF REFLECTIVE THINKING (N=24)

Dimension	Reflective Thinking Scale		
	Items	***Mean***	***SD***
HA	When I am working on some activities, I can do them without thinking about what I am doing.	1.7	0.33
	In this course we do things so many times that I started doing them without thinking about it.	1.8	0.35
	As long as I can remember handout material for examinations, I do not have to think too much.	2.3	0.12
	If I follow what the lecturer says, I do not have to think too much on this course.	3.6	0.52
U	This course requires us to understand concepts taught by the lecturer.	**4.5**	**0.71**
	To pass this course you need to understand the content.	**4.3**	**0.19**
	I need to understand the material taught by the teacher in order to perform practical tasks.	**3.9**	**0.19**
	In this course you have to continually think about the material you are being taught.	**4.2**	**0.53**
R	I sometimes question the way others do something and try to think of a better way.	**4.2**	**0.73**
	I like to think over what I have been doing and consider alternative ways of doing it.	**4.3**	**0.34**

Dimension	Reflective Thinking Scale		
	Items	***Mean***	***SD***
	I often reflect on my actions to see whether I could have improved on what I did.	**4.2**	**0.39**
	I often re-appraise my experience so I can learn from it and improve for my next performance.	**3.3**	**0.35**
CR	As a result of this course I have changed the way I look at myself.	**4.5**	**0.71**
	This course has challenged some of my firmly held ideas.	**3.6**	**0.25**
	As a result of this course I have changed my normal way of doing things.	**4.6**	**0.26**
	During this course I discovered faults in what I had previously believed to be right.	**3.1**	**0.63**

HA = habitual action dimension, U = understanding dimension, R = reflection dimension, CR = critical reflection dimension.

The results show a remarkable superiority of the students' reflective thinking skills. A higher average mean in the positive items with a lower standard deviation less than 1. Thus, the result is statistically significant in the whole scale. Through this finding, we figured out that reflective thinking is an active and continuous ability that can be developed through innovative means such as ER [34]. This training supports the related knowledge that leads to using of what they have learned in new situations [11].

The first step in the reflective approach is feedback which was clarified in the item states *"I sometimes question the way others do something and try to think of a better way"*. This is in accordance with [27] who figured out that feedback impacted students' learning outcomes, critical thinking, and reflection when they think about the ideas and solutions.

Reflection is a method of guiding analysis and personal and situational improvement through an organized process. Reflection is a notion that emphasizes an individual's awareness of prior information, experiences, and beliefs [6]. Parts of the students' comments are presented as follows:

"I liked the logical thinking in programming"

"I liked starting all the work from the beginning after the error of writing code"

"I like running the robot after the training"

C. Expectations and recommendations

After conducting the training, we were curious to identify students' expectations before they participate in the training. Interestingly, the majority of them thought it is a hard subject to learn with perceptions of complicated and advanced techniques. Remarks of some comments are as follows:

"It's just hard to put the parts together"

"I had heard it was very complicated before and then learned that joining a circle is not complicated"

"It turned out that before I had imagined robot technics with many robots and modern computers with modern equipment"

"I thought it was very difficult and complex"

ER training is significant for changing students' attitudes and expectations toward programming skills. This is consistent with the study of [31], which indicated that robotic activities performed in programming training were considered a process that facilitates learning programming. This emphasizes the important role of the instructional design of robotic activities and the teacher's role to facilitate completing the required skills.

In terms of enhancing the existing ER training for students, we encouraged them to highlight recommendations for future robotics training. Several recommendations were raised as follows: (1) increasing class hours, (2) organizing robot competitions every week, (3) allowing the individual practice, (4) encouraging the young students' involvement, and (5) increasing the difficulty level of robots. This indicates to what extent students perceived robotic activities and the promises of incorporating collaboration and competition approaches in ER training [25].

D. Practical implications

Based on the findings of this study, ER contributes to the engagement and reflective thinking skills of STEAM students. There are potentials for researchers and educators to design innovative learning activities and incorporate gamification [30] as an effective approach to enhance engagement in ER training to promote engagement. It also encourages putting efforts to search the mechanisms of the learning process of young learners [31].

Moreover, this study can be reconducted between different age groups in STEAM schools to examine the effect of these activities on computational thinking skills. Furthermore, in terms of understanding and reflection constructs, there is evidence in the study to suggest considering robotic activities in several school subjects that enable transforming knowledge and skills among these subjects, and encourage to create mental connections with the scope of engineering and related concepts [24]. This would facilitate concept absorption and applying the acquired knowledge in similar situations. On the other side, teachers play a key role in designing ER activities, especially for the students in their early school years. Hence, supporting in-service training programs is imperative to allow the implementation of the pedagogical intervention and well-design robotic and coding activities.

The results of this study are consistent with the principles of the constructivist theory in education, where the learning process takes place in a procedural manner through social negotiation between the instructor and the student, which involves a general assumption of the learning task that all students seek to achieve, as well as personal purposes for each independent student. Moreover, it relies on students confronting a real problem situation in an attempt to find solutions to it, through research, exploration, investigation, and social negotiation about evaluating and determining the most effective of these solutions [32]. Through intensive training with this study, we find that the learner plays an active role in the learning process, and his/her activity extends even after learning to the stage of self-learning evaluation. This becomes available when qualifying the learner for creativity and production, not repetition [33].

V. CONCLUSION AND FUTURE WORK

There is evidence that Educational Robotics (ER) is important in the development of academic accomplishment and scientific concepts for kids. However, there has been far too little focus on demonstrating ER effects on the development of some thinking abilities, such as reflective thinking, and social skills, such as involvement. As a result, the goal of this study was to evaluate how an intense ER training affected the development of STEM students' reflective thinking skills and participation. This study's research data come from two main sources: the engagement questionnaire and the reflective thinking measure both were applied on a five-point Likert scale and featured various items in which students expressed their agreement. The results demonstrated the effect of ER training on engagement and a remarkable superiority of the students' reflective thinking skills.

We acknowledge a few limitations in our work. Since this study recruited a small number of STEAM school students in a short time, further research could overcome the research limitations by increasing the sample size. While this empirical study provided valuable connection gathering engagement and reflective thinking, we have not yet examined longer-term evaluation, which could be an opportunity for future work. Given these limitations, future research could expand the scope of this study to explore the feedback, reflection, and teachers' needs [25] as well as parents in terms of the impact of ER training on students thinking skills. Hence, this research recommends coming up with innovative reflective thinking strategies and catalysts for engagement in ER and searching the possibilities of implementation in future learning scenarios.

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