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Comparing LEGO Spike and mBot Robot: Preliminary Data on Math and Science Enjoyment and Self-Efficacy among Lower Secondary School Students

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Abstract. Although Educational robotics (ER) has been increasingly adopted in STEM education to foster both cognitive and motivational outcomes, limited research has compared the effects of different robotics kits on students' self-efficacy. Additionally, little is known about the possible mediating role of positive emotions in this process. This quasi-experimental study has preliminarily investigated whether two ER kits, namely mBot and LEGO Spike Prime, could be associated with different levels of students' self-efficacy in STEM. Also, this study has explored whether enjoyment in math and science lessons could mediate these relationships. Sixty-six junior secondary school Italian students participated in robotics-based activities integrated in regular school lessons for 10 hours altogether, using LEGO Spike prime or mBot kit. Students filled in an online questionnaire before and after their participation, measuring self-efficacy and enjoyment via two items each.

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No statistically significant pre-post change was observed. Mediation analyses with 95%CI percentile bootstrap (5000 resamples) showed that students using LEGO Spike Prime reported higher enjoyment in science lessons post-intervention, which in turn predicted greater self-efficacy in science homework post-intervention (partially standardized regression coefficient = .21, BootSE = .11; 95% BootCI [.019 to .458]). In contrast, participation in mBot activities was directly associated with higher self-efficacy in math homework, without a mediating role of enjoyment. These preliminary findings provide some provisional indications about the relevance of choosing one robotic kit as opposed to another during ER activities, in order to maximize subject-specific self-efficacy. Also, results underscore the importance of considering both cognitive and affective (i.e., emotions) dimensions of learning when implementing ER activities in school settings.

Keywords: Educational robotics; Self-efficacy; Math; Science; STEM; emotions; mediation pathway

1. Introduction

Over the last two decades, educational interest in robotics has increased dramatically, based on its ability to provide students with a highly interactive and hands-on learning experience in the robotics domain itself, as well as in STEM domains (e.g., Bano et al., 2024; Benitti, 2012; Gunes & Kucuk, 2022; Xia & Zhong, 2018). Educational Robotics (ER) implies teaching different subjects (technical and non-technical) through robotics (Lampropoulos, 2025; Pivetti et al., 2020). Systematic reviews and metanalysis have emphasized the role of programming and robotics in supporting students' problem-solving, collaboration, creativity, and engagement across school-based learning contexts (Leavy et al., 2023; Ouyang & Xu, 2024; Sun et al., 2023).

Furthermore, ER experiences may foster students' self-efficacy by providing supportive and engaging environments for problem-solving and technological exploration. This experience gives them a strong sense of accomplishment, which directly increases their confidence in their ability to use technology to tackle complex challenges in an ever-evolving technological world (Ford et al., 2023; Himawan et al., 2024). From a theoretical perspective, ER is consistent with the Self-Determination Theory (Ryan & Deci, 2000), in that it tends to simultaneously satisfy all three basic psychological needs i.e. autonomy, competence, and relatedness, which in turn promote intrinsic motivation and interest.

Emotions experienced in academic and school settings can impact students' attention and motivation to learn, and in doing so, they can impact academic success. Specifically, research shows that positive emotions are associated with academic achievement (Xie et al., 2025). For instance, according to the fun theory perspective, activities that are perceived as enjoyable, playful and intrinsically engaging can enhance motivation, sustained engagement and positive learning outcomes (Koster, 2013; Mokhtar et al., 2023).

Despite the growing interest in ER, available research has focused on assessing the impact of ER on self-efficacy, not considering the possible mediating role of positive emotions, such as enjoyment in math and science lessons. Additionally, little research has been dedicated to comparing the impacts of different types of robotic kits on students' outcomes such as self-efficacy, so more research is needed on this issue (Pedersen et al., 2020).

Therefore, this study aims to fill this gap by exploring (1) which robotic kit between mBot and LEGO Spike prime is related to increased self-efficacy in STEM and (2) whether positive emotions such as enjoyment during the ER activities could mediate the relationship between robotic kit used and students' self-efficacy in STEM. The few available studies assessing the impact of mBot and/or LEGO robotics on students' self-efficacy failed to examine the impact of each robot separately and provided mixed results. For instance, online STEM camps based on LEGO robotics improved primary and junior secondary students' self-efficacy in a pre-post study (Chiang et al., 2022), whereas university students using LEGO Mindstorms Ev3 did not increase self-efficacy for C++ programming language compared to the traditional method (Korkmaz, 2016). Also, the role of ER in fostering self-efficacy separately in math and science has seldom been investigated.

Thus, we conducted a between-subject quasi-experimental study involving junior secondary school students, who participated in 10-hour ER activities during school hours. The sample included 66 students, divided into GROUP 1 composed by 35 students using mBot robotic kit, and GROUP 2 composed by 31 students using the LEGO Spike Prime robotic kit. Students twice filled in the same questionnaire at school during classes: once at the beginning and once at the end of the ER activities.

This study provides two contributions. First, it presents initial data comparing two robotic kits, namely mBot and LEGO robotics, in terms of STEM self-efficacy. In so doing, it provides some early indications on the more profitable kit able to foster self-efficacy in math and science, separately. Second, this study underlines the importance of positive emotions and enjoyment among junior secondary school students involved in the ER context, in order to foster STEM self-efficacy.

2. Literature Review

2.1 Educational Robotics and STEMER

Educational robotics and STEMER is considered a learning approach, based on constructivism and constructionism theories (Alimisis et al., 2007; Atman Uslu et al., 2023; Menegatti & Moro, 2010) directed to design, assemble and implement algorithms to control robots for educational purposes. ER relies on the seminal works by Papert (1980), where students programmed a robotic Logo turtle to turn and move, with a pen attached to it, creating geometric figures. Children engaging with programming a robot to move on the board had the chance to explore spatial concepts and measurements (Papert, 1980), to learn mathematics and geometry, as well as to engage in metacognitive processes. ER activities can take place in

both formal and informal environments (Tekbiyık et al., 2022) and can be applied at various educational levels (Scaradozzi et al., 2015).

In Italy, ER has progressively gained attention within STEM and digital innovation initiatives aimed at promoting computational thinking and interdisciplinary learning in school settings (MIUR, 2015; Ferrarelli & Iocchi, 2021; Scaradozzi et al., 2015). A recent systematic review published in Italian scientific journals showed that most Italian ER studies have been conducted in formal educational settings, and have mainly focused on STEM, computational thinking, learning, self-efficacy, collaboration, and motivational dimensions (Bonaiuti et al., 2022). From an instructional design perspective, Ronsivalle et al. (2019) also emphasized that ER programs can be implemented in Italian schools as interdisciplinary learning modules within existing subjects, supporting computational thinking and active student participation.

In view of this, robots are used as mediators of concepts and motivators to promote scholastic and academic achievement (particularly, but not limited to, STEM disciplines). Research has shown that ER can improve students' STEM learning, conceptualized as learning performance and learning attitudes (Ouyang & Xu, 2024). Similarly, a recent systematic review on emerging technologies in STEM education identified programming and robotics as among the most frequently used technologies, emphasizing their role in supporting students' problem-solving, collaboration, creativity, and engagement across school-based learning contexts (Leavy et al., 2023).

Likewise, the metanalysis by Sun et al. (2023) found that ER activity has a positive effect on two broad domains: (a) essential abilities including domain-specific knowledge, conceptual understanding (e.g., programming concepts, conceptualization of robotics etc.) and practice (e.g., hands-on ability), and (b) generative abilities including computational thinking skills (e.g., abstraction, algorithmic thinking, critical thinking, problem-solving), psychological processes (e.g., learning motivation, programming interest, self-efficacy, collaboration), and broader learning-related abilities (e.g., memory, attention, visuospatial abilities).

More broadly, a recent systematic review on technology-oriented STEM education highlighted that most interventions in primary and secondary schools adopt student-centred pedagogies, such as inquiry-based learning, game-based learning, and engineering design activities, with a strong focus on 21st-century skills, engagement, and interdisciplinary learning outcomes (Sun et al., 2025). In addition, a recent meta-analysis showed that educational robots exert a significant positive effect on K-12 students' computational thinking, particularly in early educational stages and when activities are implemented through design-based and collaborative learning approaches (Hong, 2024).

Despite multiple studies revealing that the ER deployment had positive effects on K12 students in terms of academic learning and learning attitudes, the applications of ER in STEM education also presented some challenges. For instance, ER may sometimes distract students from STEM learning, increase their

cognitive loads, both of which in turn can have negative learning effects (Agatolio et al., 2018; Mason & Cooper, 2013). In this vein, technical difficulties such as creating electronic circuits, encountering new concepts like resistance and sensors, and resolving wiring complexities could increase cognitive load and consequently decrease students' motivation (Akman Selcuk et al., 2024).

Additionally, factors such as students only being able to work during laboratory hours, insufficient weekly lesson hours, limited availability of robots outside of class, and large class sizes may contribute to a relative decline in students' motivation towards the course (Beug, 2012; Fagin & Merkle, 2002). Also, due to its complexity, most ER might be better suited to older students (e.g., students in further and higher education) rather than younger ones (e.g., primary school students) (Ouyang & Xu, (2024).

2.2 ER and Self-efficacy

In robotics STEM education, students are often faced with real problems that require technological solutions that they create, through Project-Based Learning methodology. Italian research has further shown that students' learning processes during ER activities involve iterative problem-solving pathways, including designing, testing, debugging, and progressively refining programming solutions (Scaradozzi et al., 2020). Project-based learning (PBL) constitutes an active, student-centred pedagogical approach defined by learner autonomy, constructive inquiry, goal-directed behaviour, collaborative engagement, communicative exchange, and reflective practice, all situated within authentic, real-world contexts (Kokotsaki et al., 2016).

In this vein, ER provides a platform for students to apply their technical knowledge in relevant and significant contexts. More broadly, educational technology research has shown that the effectiveness of technology-enhanced learning environments depends not only on the technology itself, but also on factors such as perceived usefulness, self-efficacy, facilitating conditions, and institutional support (Feng et al., 2025; Granić, 2022). Accordingly, ER experiences may foster students' confidence by providing supportive and engaging environments for problem-solving and technological exploration. This experience gives them a strong sense of accomplishment, which directly increases their confidence in their ability to use technology to tackle complex challenges in an ever-evolving technological world (Himawan et al., 2024).

In line with the original work by Bandura (1997), some studies considered self-efficacy as an antecedent of school engagement (Murphy et al., 2019), leading to a virtuous cycle in which self-efficacy could lead to greater engagement and more positive academic results, which could in turn lead to increased self-efficacy. When students engage in robotics-based projects, they understand how robots work and learn to solve complex problems by collaborating with peers. In this process, they naturally increase their confidence in using technology and in facing future technological challenges (Tsai et al., 2021).

Indeed, previous scholars have shown that robotics-based activity had significant effects on the self-efficacy of primary and secondary school students (Ford et al., 2023; Isabell & Mentzer, 2025). Along the same lines, kindergarten children who participated in a robotics program reported greater confidence in building, following visual instructions, and solving problems compared to the control group following a standard curriculum. These findings indicate that early robotics can enhance both beliefs of capability and tangible problem-solving skills in early childhood (Zviel-Girshin & Rosenberg, 2025).

Zhang (2025) compared self-efficacy, autonomy, and motivation between an experimental group of university students involved in Robot-Assisted Learning (RAL) and a control group taught using conventional teaching. Results indicated significant developments in self-efficacy, autonomy, and motivation for the group exposed to RAL. RAL provided immediate feedback and motivational incentives able to cultivate a positive and engaging educational experience. Crowder & Whittle (2022) investigated self-efficacy and interest in pursuing STEM classes, using a pre-post survey. They found a small non-significant increase in the intention to pursue STEM and in self-efficacy. In a quasi-experimental study among first grade students, Zviel-Girshin & Rosenberg (2025) found that children who participated in the inquiry-based robotics project demonstrated significantly higher problem-solving self-efficacy and more positive attitudes toward peer collaboration, while also being more likely to see the relevance of robotics vis-à-vis real-world problems, as compared to the control group.

Following the Self-Determination Theory (SDT; Deci & Ryan, 2013), ER environments tend to simultaneously satisfy three basic psychological needs: students experience autonomy through design choices and problem-solving strategies, competence through the immediate and tangible feedback provided by the robot's functioning, and relatedness through collaborative teamwork during building and programming tasks (Anwar et al., 2019; Zhang, 2025). Additionally, within the SDT framework, the fulfilment of these basic psychological needs is theorized to promote intrinsic motivation, which manifests phenomenologically as interest and enjoyment in the activity (Ryan & Deci, 2000). When experienced during mathematics and science lessons, enjoyment signals that the learning environment is effectively supporting students' psychological needs (Pekrun & Linnenbrink-Garcia, 2012), suggesting that it may constitute a critical mediating mechanism through which ER fosters more distal outcomes, including students' self-efficacy in autonomous academic tasks such as homework.

2.3 ER, emotions and self-efficacy

The school setting provides an environment for a variety of emotional experiences, that in turn can deeply impact academic achievement (Pekrun & Linnenbrink-Garcia, 2012; Tan et al., 2021). Emotions can impact students' attention and motivation to learn, which in turn can impact academic success. For instance, positive emotions such as enjoyment of learning and pride could assist in visualizing goals and facilitating problem-solving (Pekrun et al., 2002), whereas negative emotions like excessive anxiety, hopelessness, and boredom are detrimental to educational attainment (Zeidner, 2014). The review by Tan et al.

(Tan et al., 2021) supported the idea that positive academic emotions can promote learning effects. Likewise, the recent meta-analysis by Xie et al. (Xie et al., 2025) confirmed that positive emotions were related to successful academic performance.

According to the control-value theory of achievement emotions (CVT; Pekrun, 2024; Tze et al., 2022), the experience of different achievement emotions depends on how much control individuals feel they have over achievement activities that have relevance or value for them. A systematic review on 186 studies based on the CVT found a positive relation between enjoyment and outcome constructs such as appraisal, achievement and cognitive support (Loderer et al., 2020).

Moreover, the fun theory perspective offers an additional lens through which to understand the role of positive emotions in learning contexts. According to this framework, activities that are perceived as enjoyable, playful and intrinsically engaging can enhance motivation, sustained engagement and positive learning outcomes (Koster, 2013; Mokhtar et al., 2023). Indeed, enjoyment could be conceptualized as a functional mechanism that supports attention, persistence and active participation. In hands-on and experiential learning environments, such as ER, fun-related experiences can thus encourage deeper cognitive engagement and self-regulatory processes (Tisza & Markopoulos, 2021).

In ER research, positive emotions have been labelled using closely related terms such as learning enjoyment, satisfaction, perceived playfulness, interest, and affective states (Liu & Wu, 2024; Rocha et al., 2025; Yang et al., 2023; Zhang & Yan, 2025). For instance, Yang et al. (2023) found that learning enjoyment led to higher problem decomposition, algorithm design, and algorithm efficiency skills in a sample of first-year university students engaged in augmented reality technology. These constructs capture students' positive affective experiences during hands-on robotics activities and are theoretically consistent with CVT frameworks.

Emotion and self-efficacy have long been viewed as two variables that are highly correlated (Kirk et al., 2008; Mesurado et al., 2018). Some studies have been devoted to exploring the relationship between positive emotions and self-efficacy during ER activities (An et al., 2022). In line with the learning-by-doing approach, if the robotics experiences are perceived as positive, then this could foster perceived self-efficacy in task-specific domains. For instance, Shang et al. (2023) found that third- and fourth-grade students taking part in a camp program for three consecutive days significantly increased their self-efficacy and CT. An et al. (2022) found that positive emotions and technological self-efficacy play a mediating role between technology acceptance and self-directed learning in a sample of middle school Chinese students. Tang et al. (2024) via convergent mixed methods design found that integrating robotics-based intervention in language arts classes significantly improved rural students' computer science self-efficacy. Qualitative findings showed that mastery experience and embodied learning provided by robotics activities contributed to improving self-efficacy.

Moreover, recent research in ER and inquiry-based STEM education has increasingly highlighted the close interconnection between emotional engagement, mastery experiences, and students' self-efficacy beliefs. Within hands-on and inquiry-oriented learning environments, positive affective experiences such as enjoyment, curiosity, and engagement may foster students' perceptions of competence and confidence in problem-solving activities. In this regard, Muñoz-Losa and Marcos-Merino (2024) found that interactive and manipulative STEM activities significantly increased both positive emotions and self-efficacy among pre-service teachers, with positive correlations emerging between affective and self-efficacy-related variables. Likewise, inquiry-based robotics activities have been shown to enhance children's confidence, engagement, perseverance, and enjoyment through collaborative and mastery-oriented learning processes (Zviel-Girshin & Rosenberg, 2025).

In particular, the authors argued that authentic and open-ended robotics challenges may provide students with meaningful mastery experiences, thereby strengthening their problem-solving confidence and self-efficacy beliefs (Zviel-Girshin & Rosenberg, 2025). Similarly, Tang et al. (2024) found that mastery experiences and embodied learning during robotics-based activities contributed to improvements in students' computer science self-efficacy, whereas Shang et al. (2023) reported increases in both computational thinking self-efficacy and satisfaction following participation in a robotics camp. Along the same lines, Zhang (2025) observed that Robot-Assisted Learning environments providing immediate feedback and motivational support significantly enhanced students' self-efficacy and learning motivation. Furthermore, Himawan et al. (2024) suggested that applying technological knowledge through meaningful robotics-related challenges may strengthen students' confidence in dealing with complex technological tasks. Overall, these findings support the idea that positive emotional experiences during ER activities may represent a significant psychological mechanism by means of which robotics-based learning environments foster students' self-efficacy beliefs in STEM-related domains.

Importantly, the extent to which robotics-based activities foster engagement, enjoyment, and self-efficacy may also depend on the specific characteristics of the robotics platform adopted. Educational robotics platforms can differ substantially in terms of construction flexibility, programming interface, sensor integration, level of scaffolding, and opportunities for hands-on experimentation and collaborative problem-solving (Gümüş et al., 2023). In particular, robotics kits involving active construction and iterative manipulation appear to promote greater creativity, engagement, and student-centred exploration (Stoffová et al., 2021). Such differences may shape not only students' cognitive learning processes, but also their emotional involvement and perceived competence during robotics-based activities. However, despite the increasing use of ER in STEM education, empirical studies directly comparing different robotics platforms within the same educational context are still limited.

3. The Present Study

3.1 Rationale and Research Questions

Despite the growing interest in ER, its possible role in fostering students' STEM self-efficacy is still unclear. Available research has focused on assessing the impact of ER on self-efficacy, without considering the possible mediating role of positive emotions, such as enjoyment in math and science lessons. Additionally, little research has been dedicated to comparing the impacts of different types of robotic kits on students' outcomes such as self-efficacy, so more research is needed on this issue (Pedersen et al., 2020).

Given the lack of studies connecting robotic kit, emotions and self-efficacy, this study aims to fill this gap by preliminarily exploring the possible role of two types of robots, namely mBot and LEGO Spike Prime on the students' self-efficacy in STEM. The robotic devices mBot and LEGO kit are commonly used in ER activities and research with primary and junior secondary school children (Scaradozzi et al., 2019). Studies investigating the impact of mBot and/or LEGO robotics on students' self-efficacy failed to examine the possible role of each robot separately, and the few available provided mixed results. For instance, self-efficacy on videogaming increased significantly in the combined LEGO robotics/gaming environment group as compared with the gaming-only context (Leonard et al., 2016).

Online STEM camps based on LEGO robotics improved primary and junior secondary students' self-efficacy in a pre-post study (Chiang et al., 2022). A short, intensive coding and robotics training involving both MakeBlock, mBot robot set, and the LEGO WeDo 2.0 Robotic was provided to a sample of middle school students. Pre-post data showed an improvement in CT self-efficacy skills (Özmutlu et al., 2021). After 8-weeks of activities with the mBot educational robot set, the experimental group of junior secondary school students scored higher in programming self-efficacy as compared to the control group who did not participate in any robot activities (Hangün & Türel, 2025).

However, some studies found no improvement in self-efficacy. For instance, university students using LEGO Mindstorms Ev3 did not increase self-efficacy for C++ programming language compared to the traditional method (Korkmaz, 2016). LEGO robotics instructions through scaffolding did not lead to a higher level of programming self-efficacy as compared to LEGO robotics direct instructions in a sample of primary school students (Fanchamps et al., 2021). Also, technology self-efficacy did not increase pre-post being engaged in LEGO robotics and creating games using Scalable Game Design software among junior secondary school students (Leonard et al., 2016).

Considering the limited availability of empirical research on these topics, we formulated two exploratory research questions guiding this study:

RQ1: Which robotics kit, between mBot and LEGO Spike prime, would be related to increased self-efficacy in STEM? We took into consideration two similar but different types of robotics kit (i.e., mBot and LEGO Spike) on the students' self-efficacy in math and/or science. In accordance with the Constructionism learning

theory, it has been argued that using crafts and recycled materials to build a robot from scratch would be more effective than using structured materials (Fortunati et al., 2022). Within the learning-by-doing approach, Fortunati et al. (2014) found that the concrete experience of building a simple robot activated affective, emotional, physical, and social dimensions in children and brought them to the development of a more sophisticated conceptualization of robots. Also, we argue that the positive effect of a scaffold learning environment, such as ER, could spill over into related processes such as STEM self-efficacy. In this vein, we advance a tentative exploratory hypothesis according to which LEGO robotic kit would lead to greater STEM self-efficacy as compared to mBot.

RQ2: Could positive emotions mediate the relationship between robotics kit used and self-efficacy in math and/or science homework? Based on the prediction of CVT, SDT and fun theory, we expected that enjoying the ER activity would lead to greater self-efficacy in the STEM school subjects (Tisza & Markopoulos, 2021). We consider enjoyment as a possible mediator between the robotics kit and self-efficacy, in that an increase in positive emotions during ER activities would lead to an increase in STEM homework self-efficacy among students.

Since our theoretical framework primarily describes a process through which learning environments influence motivational outcomes, a mediation model was considered more appropriate than a moderation one. In other words, positive emotional experiences during ER activities may represent a relevant psychological mechanism through which robotics-based learning environments foster students' self-efficacy beliefs in STEM-related domains. Accordingly, enjoyment was expected to explain the mechanism through which different robotics kits may affect students' STEM self-efficacy, rather than alter the strength of this relationship. A graphical representation of RQ2 is reported in Figure 1.

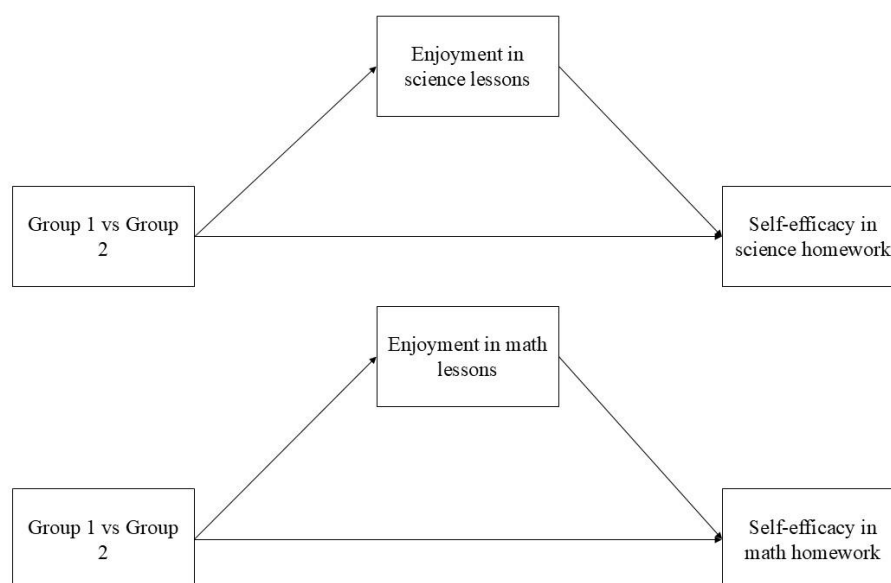


Figure 1: Hypothesized mediation models

4. Methods

4.1 Participants and Procedure

To achieve these aims, we conducted a between-subject quasi-experimental study involving junior secondary school students, who participated in ER activities during school hours in Spring 2025. In line with the natural experiment methodology, the exposure to the event of interest, that is robot-supported STEM activities, was implemented within a real-world environment where those processes naturally operate, such as school classrooms and was not manipulated by the researcher (Crane et al., 2020; Leatherdale, 2019).

The experiment included teachers from 9 classes belonging to 5 junior secondary schools. Teachers were given training in planning ER interventions with their children and supervision along the implementation. The teachers themselves, who best knew the children and their class group, designed and facilitated the activities. As a research team, we monitored the different aspects of the activities via online and face-to-face meetings with the teachers. Teachers were instructed to design a STEM-oriented educational activity involving coding a moving robot of their choice, for at least 10 hours during class.

The full sample included 128 students who volunteered to participate in our data collection. Among the 9 classes, 7 (two 6th grade, four 7th grade and one 8th grade) implemented robotic activities with mBot, whereas 2 classes (one 6th grade and one 7th grade) used LEGO Spike Prime. Given the disproportionate number of classes using mBot as compared to those using LEGO Spike Prime, we had to perform a selection of intervention classes. We included in the final sample the only 2 classes using LEGO Spike Prime (one 6th grade and one 7th grade). In order, to select two comparable classes (one 6th grade and one 7th grade) using mBot, we randomly selected two classes using a computer-generated random number (Musa et al., 2016; Pelgrims et al., 2023). Among the four available 7th grade classes, the class associated with the highest generated number was included in the study.

The same applies for one 6th grade class, out of the two-6th grade eligible classes. Additionally, we included in the final sample the only 2 classes using LEGO Spike Prime (one 6th grade and one 7th grade). Thus, we obtained GROUP 1 composed by 2 randomly selected classes (one 6th grade and one 7th grade) using mBot robotic kit, and GROUP 2 composed by the only 2 classes (one 6th grade and one 7th grade) available, using the LEGO Spike Prime robotic kit. The final sample included 66 students (female = 50%). Ages ranged from 11 to 15 years ($M = 11.74$, $SD = .70$), see Table 1.

All the students were asked to fill in the same questionnaire on Qualtrics platform at school during classes twice: once at the beginning and once at the end of the ER activities. No attrition occurred during the study: all 66 participants provided complete data at both pre- and post-intervention. As the dataset contained no missing values, no imputation procedures were required.

The research project was approved by [Blinded for peer-review] and complies with the data protection regulations in [Blinded for peer-review]

4.2 Robotic Activities

In this study, GROUP 1 used mBot, that is a pre-designed metal/plastic kit with essentially one constructive layout, whereas GROUP 2 used LEGO Spike Prime kit, that is a modular robotic kit which allows a wide variety of layouts and can be built at every use. The two robots are similar in terms of programming as both robotic devices can be programmed either in a block-based language or in Python. Additionally, they are similar in terms of sensor equipment. However, mBot is a ready-to-use robot once built the first time and is less customizable as compared to the LEGO Spike Prime. The great advantage of the LEGO System is its versatility in terms of construction, which allows students to build a prototype, test it and modify it countless times during the same lesson. In this way, it allows for better understanding of the different parts of the robot as the students can directly observe the sensors and actuators while building the robot. In contrast, the shape of the mBot robot remains virtually fixed and requires the use of screwdrivers for assembly.

GROUP 1 – mBot - Description of the robotics intervention

This group was involved in more complex programming and robotic activities such as reverse engineering, followed by a reflection phase, as compared to GROUP 2. Specifically, the intervention started with introductory and unplugged activities focused on understanding the role of precise instructions in controlling a robot. Students then engaged in pair-based block programming tasks using Blockly Games to learn core concepts such as sequencing, loops, and conditional statements. Subsequently, students worked with Scratch to design simple interactive projects and to practice code analysis through reverse-engineering tasks. The intervention ended with hands-on robotics activities using mBot, during which students programmed the robot to solve distance-based and maze-navigation challenges, gradually integrating sensors and conditional logic. The intervention ended with a short reflection phase to support learning consolidation.

GROUP 2 – LEGO Spike Prime - Description of the robotics intervention

Using LEGO SPIKE Prime, students engaged in activities that combined robot construction and block-based programming. The first phase consisted of unplugged and visual programming activities focused on CT and algorithmic reasoning. Initial tasks focused on assembling a basic robot structure and programming simple movements (e.g., forward motion, turns, geometric paths), followed by activities involving distance and colour sensors. Students worked in stable, heterogeneous groups throughout the intervention. Peer tutoring by older students supported group work and facilitated learning. The intervention emphasized hierarchical thinking, sequencing of instructions, and collaborative problem-solving. The activities adopted a flexible design, allowing task simplification when needed, and conceptualized error as a constructive learning element. A detailed description of robotic activities is provided in Supplementary material.

Table 1: Characteristics of the two groups

	GROUP 1 (6th & 7th grade)	GROUP 2 (6th & 7th grade)
No. of students	14 + 21 = 35	13 + 18 = 31
Robotics kit	mBot	LEGO Spike Prime
Programming software	mBlock	SPIKE App
Type of robot	Pre-designed kit	Needs to be built
Working group in lessons	2 students per group	2/3 students per group
Duration	10 hours	10 hours

4.3 Measures

The questionnaire included:

- Self-efficacy in math and science homework. Two items measured self-efficacy in math and science homework ("I can do my math homework"; "I can do my science homework"; 1 = Strongly disagree, 2= Disagree, 3= Agree, 4 = Strongly agree; (Kier et al., 2014). The same two items were assessed both pre and post intervention.
- Enjoyment in math and science lessons. Two items measured enjoyment in math and science ("I enjoy math lessons"; "I enjoy science lessons"; 1 = Strongly disagree, 2= Disagree, 3= Agree, 4 = Strongly agree; (Burack et al., 2019). The same two items were assessed both pre and post intervention.

Moreover, socio-demographic data concerning age and gender (coded as 1= man and 2= woman) were collected in the pre-intervention questionnaire.

5. Results

5.1 Preliminary Analyses

As preliminary analyses, we checked for the normality of the distribution concerning enjoyment in math and science lessons pre- and post-intervention and self-efficacy in math and science homework pre- and post-intervention. Mean, standard deviation, skewness and kurtosis about the above-mentioned variables are reported in Table 2. All the analyses were conducted using SPSS v. 21.

Table 2: Descriptive statistics on the study variables

n=66	M	SD	SK	KU
ENJSCPRE	3.18	.63	-.15	-.51
ENJSCPOST	3.15	.66	-.50	.68
ENJMATHPRE	3.09	.75	-.37	-.50
ENJMATHPOST	3.09	.79	-.72	.35
SELFEFFSCPRE	3.29	.62	-.29	-.60

SELFEFFSCPOST	3.21	.66	-.59	.70
SELFEFFMATHPRE	3.18	.76	-.53	-.38
SELFEFFMATHPOST	3.17	.71	-.77	1.09

Note. ENJSCPRE= *Enjoyment in science lessons pre-intervention*; ENJSCPOST= *Enjoyment in science lessons post-intervention*; ENJMATHPRE= *Enjoyment in math lessons pre-intervention*; ENJMATHPOST= *Enjoyment in math lessons post-intervention*; SELFEFFSCPRE= *Self-efficacy in science homework pre- intervention*; SELFEFFSCPOST= *Self-efficacy in science homework post-intervention*; SELFEFFMATHPRE= *Self-efficacy in math homework pre- intervention*; SELFEFFMATHPOST= *Self-efficacy in math homework post- intervention*; SK= *Skewness*; KU= *Kurtosis*

As no extreme values were detected, such as nearly zero standard deviations or skewness and kurtosis higher than |2| (Barbaranelli, 2007), the normality of the distribution was assumed.

Furthermore, we checked whether the two groups were balanced in terms of age, gender, enjoyment in math and science lessons pre-intervention and self-efficacy in math and science homework pre-intervention. In detail, results from the one-way ANOVAs revealed that the two groups were balanced in terms of enjoyment in science lessons pre-intervention: $F(1,65) = 3.00, p = .088$ and enjoyment in math lessons pre-intervention: $F(1,65) = 1.87, p = .176$. Furthermore, results from one-way ANOVAs revealed that the two groups were balanced in terms of self-efficacy in science homework pre-intervention: $F(1,65) = .00, p = .976$ and self-efficacy in math homework pre-intervention: $F(1,65) = .72, p = .398$. A one-way ANOVA revealed no significant differences between the two groups in terms of age: $F(1,65) = .47, p = .494$. Finally, the two groups were balanced in terms of gender: $\chi^2(1,64) = .567, p = .451$. Therefore, the previous measures were not included in the following mediation model.

5.2 Mediation Analyses

In order to investigate RQ1 and RQ2, two mediation models were tested using model 4 of the macro-PROCESS v.4.2. for SPSS V.21 (Hayes, 2018). The two mediation models were tested with 95%CI percentile bootstrap and 5000 resamples. Specifically, in the first mediation model, group was included as the independent variable, enjoyment in science lessons post-intervention as mediator, and self-efficacy in science homework post-intervention as dependent variable. Figure 2 illustrates the results of the mediation model examining the relationships between the robotics groups, enjoyment in science lessons post-intervention, and self-efficacy in science homework post-intervention, including the estimated a path, b path, direct and total effects.

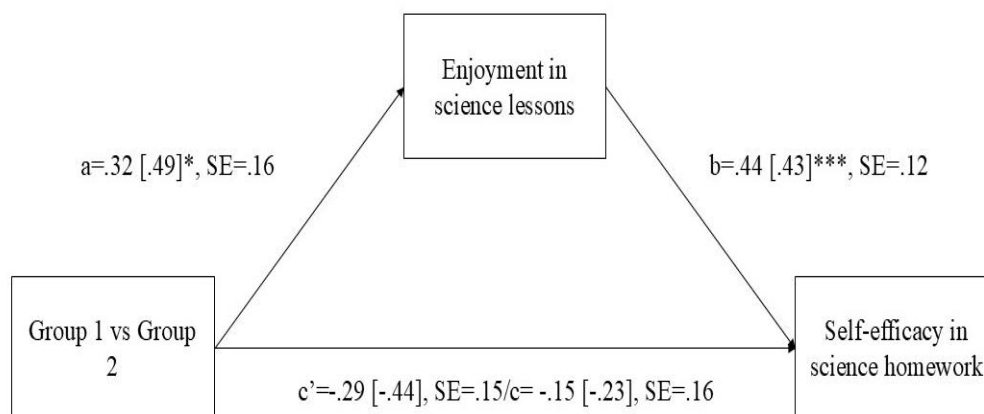


Figure 2: The mediation model on self-efficacy in science

Notes. Mediation model with enjoyment in science lessons post-intervention as the mediator and self-efficacy in science homework post-intervention as the dependent variable. Note. Group 1 = mBot; Group 2 = LEGO Spike Prime. Values in brackets represent standardized regression coefficients. c' = direct effect; c = total effect. * $p < .05$. ** $p < .01$. *** $p < .001$.

As a first step, we included groups as the independent variable and enjoyment in science lessons post-intervention as the dependent variable. This model was significant and accounted for 6% of the variance of the outcome ($F=4.08$, $p=0.0473$; $R^2=0.06$), showing that students involved in the activity with LEGO Spike Prime (i.e., Group 2) - enjoyed doing science lessons post-intervention more than the students involved in the activity with mBot (Group 1) (see path a, Figure 2).

In the second step, we included groups and enjoyment in science lessons post-intervention as independent variables and self-efficacy in science homework post-intervention as dependent variable. The model was significant ($F=7.40$, $p=0.0013$; $R^2=0.19$) and accounted for 19% of the variance of self-efficacy in science homework post-intervention. In detail, enjoyment in science lessons post-intervention significantly predicts self-efficacy in science homework post-intervention (see path b, Figure 2).

The indirect effect of groups on self-efficacy in science homework post-intervention through enjoyment in science lessons post-intervention was significant (*point estimate*= .14, *BootSE*= .07; 95%*BootCI* [.012 to .316]) (*partially standardized regression coefficient*= .21, *BootSE*= .11; 95%*BootCI* [.019 to .458]), thereby showing that the students involved in the LEGO Spike Prime activity (Group 2) - compared to the students involved in the mBot activity (Group 1) - enjoyed more the science lessons post-intervention and this in turn leads to higher self-efficacy in science homework post-intervention. Neither the direct nor the total effects were significant (see path c and c' , Figure 2).

However, Hayes (2009) and other researchers (MacKinnon et al., 2000) have argued that demonstrating a significant total effect is not a prerequisite for testing indirect effects. Hayes (2009, pp. 414–415) emphasized that failing to explore indirect pathways when the total effect is non-significant may lead researchers to overlook meaningful, substantive, or theoretically informative mechanisms that mediate the relationship between X and Y. In line with this assumption and our

findings, previous studies have already been published with significant indirect effects without evidence of significant total or direct effects (e.g., Clemente et al., 2024, 2025; Marchetti et al., 2024).

Additionally, a second mediation model was tested, including groups as the independent variable, enjoyment in math lessons post-intervention as mediator, and self-efficacy in math homework post-intervention as the dependent one. Figure 3 illustrates the results of the mediation model examining the relationships between the robotics groups, enjoyment in math lessons post-intervention, and self-efficacy in math homework post-intervention, including the estimated a path, b path, direct and total effects.

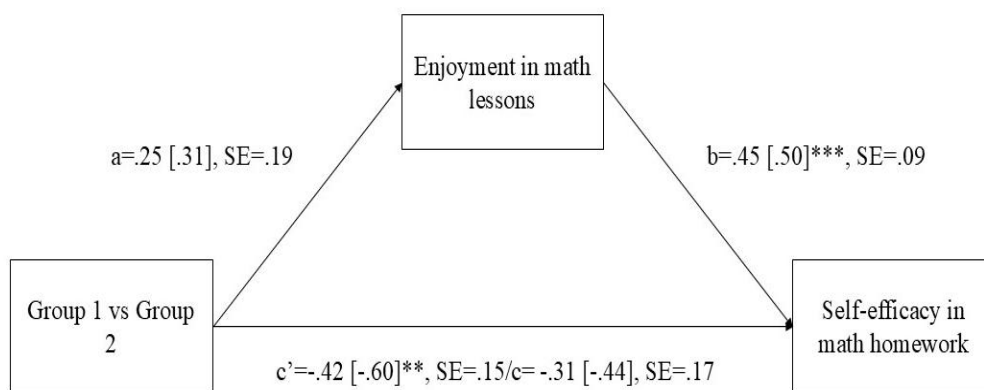


Figure 3: The mediation model on self-efficacy in math

Notes: Mediation model with enjoyment in math lessons post-intervention as the mediator and self-efficacy in math homework post-intervention as the dependent variable. Note. Group 1 = mBot; Group 2 = LEGO Spike Prime. Values in brackets represent standardized regression coefficients. c' = direct effect; c = total effect. * $p < .05$. ** $p < .01$. *** $p < .001$.

Akin to the first mediation model tested, we included groups as independent variable and enjoyment in math lessons post-intervention as dependent variable. This model was not significant and accounted for 2% of the variance of the outcome ($F=1.68$, $p=.198$; $R^2= 0.02$). Therefore, no significant differences were observed between the two groups regarding enjoyment in math lessons (see path a, Figure 3).

In the second step, we included groups and enjoyment in math lessons post-intervention as independent variables and self-efficacy in math homework post-intervention as the dependent variable. The model was significant ($F=13.45$, $p<.001$; $R^2=0.29$) and accounted for 29% of the variance of self-efficacy in science homework post-intervention. In detail, enjoyment in math lessons post-intervention significantly predicts self-efficacy in math homework post-intervention (see path b, Figure 3). The indirect effect of groups on self-efficacy in math homework post-intervention through enjoyment in math lessons post-intervention was not significant (*point estimate*= .11, *BootSE*= .09; 95%*BootCI* [-.05 to .31]) (*partially standardized regression coefficient*= .16, *BootSE*= .13; 95%*BootCI* [-.08 to .43]), showing therefore that groups did not have an effect on self-efficacy in math homework post-intervention through enjoyment in math lessons post-intervention. Furthermore, while the total effect was not significant (see path c,

Figure 3) the direct effect was significant (see path c' , Figure 3). Specifically, students involved in the mBot activity (Group 1) reported higher self-efficacy in math homework post-intervention compared to Group 2.

5.3 Repeated Measure ANOVA

Finally, we conducted repeated measures ANOVAs to examine whether significant effects of time and the time*group interaction emerged for self-efficacy in math homework and self-efficacy in science homework from pre- to post-intervention. Results revealed that both the effect of time $F(1,64) = .800, p = .374$ and time*group $F(1,64) = .800, p = .374$ on self-efficacy in science homework was not significant. Similar results were observed concerning self-efficacy in math homework, in detail: time $F(1,64) = .043, p = .837$, and time*group $F(1,64) = .646, p = .425$.

6. Discussion

This study investigated whether the use of two robotics kits, namely mBot and LEGO Spike, would be related to different levels of students' self-efficacy in science and math homework. The two robots are similar in terms of programming environment and in terms of sensor equipment. However, the LEGO Spike is more versatile in terms of construction, allowing students to build a prototype and modify it repeatedly, whereas mBot robot remains virtually fixed once built the first time.

Moreover, this study explored the role of positive emotions, detected after ER activities, in mediating the relation between the robotics kit and self-efficacy in science and math homework post-intervention. In other words, in the two groups we studied whether enjoying the ER activity would be related to greater self-efficacy in school subjects. Moreover, we aimed to explore whether the implementation of ER activities would be related to higher self-efficacy in math and science homework from pre- to post-intervention.

Our non-significant findings pre-to post intervention in self-efficacy could be related to the brief duration of ER intervention to obtain meaningful change in children. Given the 10-hour robot-supported STEM activities, it is possible that such limited exposure did not influence children's STEM interest in a measurable way (Agatolio et al., 2019). While findings revealed no significant pre-to post change in self-efficacy in math and science homework, the results of the mediation models showed that students involved in LEGO Spike Prime activity reported, post-intervention, higher enjoyment of the science lessons compared to the students in the mBot group, which in turn led to higher self-efficacy in science homework post-intervention. This is consistent with previous findings revealing that a robotics STEM camp involving the LEGO kit positively affected the self-efficacy of primary school students (Chiang et al., 2022; Shang et al., 2023).

In this regard, the highlighted relationship between the LEGO kit vs.mBot is also grounded in the greater enjoyment in the experience of building a simple LEGO robot (Fortunati et al., 2022), as compared to the more structured and complex activities implemented with the mBot group. In this sense, the enjoyment that

students experienced during LEGO-based activities may have played a crucial motivational role in fostering their engagement with science-related tasks. As a scaffolded learning environment, LEGO robotics promotes manual skills, creativity, and active exploration, stimulating greater enjoyment during science lessons.

Enjoyment is known to enhance intrinsic motivation and persistence in learning contexts, facilitating deeper cognitive involvement and more positive perceptions of one's own competence. Indeed, Merkouris and Chorianopoulos (2015) found that junior secondary school students expressed more positive emotions while programming with LEGO Mindstorms robotics than with Scratch on a desktop computer. In our study, when children perceived an activity as playful, creative, and emotionally rewarding, they were more likely to internalize the learning experience and transfer this sense of mastery to individual academic tasks outside school time, such as science homework. Therefore, the greater enjoyment associated with the LEGO Spike Prime activity may represent a key psychological mechanism underlying the observed increase in science self-efficacy. Since this spill-over effect had not been pointed out previously, it can be considered a novel contribution of the present study.

As for the mBot group, the experience of participation in ER activities was positively and directly associated with greater self-efficacy in math homework post-intervention, with no mediating role of enjoyment post-intervention. In the mBot group, the students did not spend time building the robot as it was a built-in one. Additionally, the students in this group engaged in more complex programming and robotic activities, such as reverse engineering, as compared to the students in the LEGO Spike group. We can speculate that the STEM competences learned during programming activities may have contributed to improving their self-efficacy in math homework.

However, this association was not mediated by enjoyment in math lessons, suggesting that the relationship between the mBot experience and math homework self-efficacy may operate through mechanisms other than those captured in the present study. It is worth noting that preliminary analyses showed that the two groups did not differ significantly on either enjoyment in science and math lessons or science and math homework self-efficacy at pre-intervention. Within the mediation model, (Authors: which of the two groups is this?) group significantly predicted post-intervention enjoyment in science lessons, in favour of LEGO Spike. Given the absence of baseline differences, this post-intervention difference is more plausibly associated with the activities than with pre-existing group characteristics.

Enjoyment, in turn, was associated with science homework self-efficacy post-intervention, yielding a significant indirect effect. The repeated-measures ANOVAs likewise revealed no significant pre-post change in homework self-efficacy in either domain (i.e., mathematics and science). These analyses address different questions. The repeated-measures ANOVAs test whether average scores shift over time, or whether the two groups follow different trajectories, whereas the mediation captures a more specific cross-sectional route: at post-intervention,

group was associated with enjoyment, and enjoyment was in turn linked to science homework self-efficacy. Only part of the variance in self-efficacy travels along this route, so a modest indirect effect can readily coexist with non-significant time and time $\times$ group effects, particularly with a small sample and single-item measures, which reduce sensitivity to change-based tests. The present findings should therefore be read as evidence of a motivational-affective pathway detected at post-intervention, rather than as a change in enjoyment or self-efficacy brought about by the activities over time. As the associations rest on concurrent post-intervention measures, confirming this pathway will require larger, longitudinal randomised designs with repeated, multi-item assessment of both the mediator and the outcome.

In summary, given the absence of significant mean differences in the two groups concerning enjoyment and self-efficacy pre-intervention in both math and science, the ER improved enjoyment in science lessons in the LEGO Spike group - compared to the Mbot group, and this improvement in turn is related to higher self-efficacy in doing science homework. Furthermore, the mBot group- compared to the LEGO Spike group, reports higher self-efficacy in math homework post-intervention, without evidence of mediation of enjoyment in math lessons post-interventions. One possible explanation for these different paths may lie, on one side, in the alignment between LEGO Spike activities and the laboratory-based nature of science lessons. The nature of LEGO-supported robotics laboratories is consistent with the experimental and inquiry-oriented character of science education in junior secondary school.

Accordingly, participation in ER with LEGO Spike may foster greater enjoyment following the activities, which in turn promotes higher science self-efficacy. On the other hand, the more built-in structure of mBot and the greater cognitive complexity of the associated ER activities may have limited this enjoyment-based process in science homework. Instead, mBot-supported activities appear to be directly related to higher self-efficacy in math homework, independently of enjoyment. It is possible to speculate that, due to his structure, mBot- compared to LEGO Spike - might provide students with a higher activation in mathematical tasks, contributing to increasing their perception of competence in this domain.

Whereas the majority of studies on ER and STEM engagement has treated STEM as a single, undifferentiated construct, without considering its different facets, our study has investigated the relations between of ER activities and self-efficacy in math and science separately. This approach has made it possible to disentangle the subject-specific pathways linking robot-supported activities to each domain, and to clarify the mediating role of enjoyment for science, but not math, self-efficacy. We consider this as another novelty of the study, even though it should be taken with caution, as only two STEM domains were investigated. As great importance is allocated to math and science subjects in the Italian school system, we have preliminarily explored those STEM dimensions. Nonetheless, future studies could also explore the Technology and Engineering dimensions of STEM.

6.1 Study Limitations

The study is not without limitations. Firstly, given the small sample size, our findings should be considered as preliminary and should be interpreted with caution (i.e., increased risk of type II error): although the indirect effect with 95%CI percentile bootstrap and 5000 resamples reached significance, the results warrant replication in a larger sample. Moreover, the quasi-experimental design adopted does not allow the random assignment of participants into the two conditions and limits the internal validity of the study. However, as previously stated, randomization is not feasible within naturally occurring educational settings such as school classes or sociodemographic groups (e.g., age, gender, SES) (Crane et al., 2020). The sample size was thus determined by the number of participating classrooms.

Second, several constructs were assessed using a limited number of items, including single-item measures. This approach is relatively common in STEM research (Fletcher et al., 2024; Küçükaydın et al., 2024; Morris et al., 2019; Roller et al., 2020; Ulum, 2022) and may reduce response burden and fatigue. Moreover, brief assessment formats are often adopted in school-based research contexts to minimize disruption to classroom activities and hold students' attention during data collection (Fletcher et al., 2024). Nonetheless, we acknowledge that the use of single items measures precludes estimation of reliability and is more likely to attenuate the observed coefficients. Therefore, future studies would benefit from employing more comprehensive validated scales, including those specifically developed to assess robotics-related self-efficacy (Agus et al., 2025; Tsai et al., 2021; Yanış & Yürük, 2020).

Additionally, we must acknowledge that GROUP 1 engaged in more complex programming activities than GROUP 2, and, consequently, we could not rule out the possibility that any difference could be due to the different levels of complexity rather than the robotic kit itself. This fundamental limitation prevents causal inferences and underlines the preliminary nature of the study. Furthermore, given the lack of uniformity between the two activities carried out, our data cannot entirely rule out the possibility that the results obtained were due exclusively to the robot kits used, or that the instructional design jointly influenced outcomes, an aspect that warrants further investigation, for instance, considering the standardization of instructional conditions across groups.

In addition, future research should implement ER activities with the two robotics kits at similar levels of complexity to be able to draw causal conclusions concerning the impact of each kit on self-efficacy. Furthermore, although self-efficacy and enjoyment were measured, no actual learning gains, performance improvements, or skill development were assessed. Future studies should be conducted including pre-post content knowledge assessments, to strengthen the educational implications of the findings. In addition, other emotional dimensions such as satisfaction and task interest should be considered in future studies to fully capture affective experiences, as well as potential mediators, such as perceived competence or mastery experience.

Moreover, despite being beyond the scope of the present study, we have not fully deepened the role of gender and previous technology experience. In future studies, the moderating role of gender and controlling for previous technology experience could be further explored to enrich and strengthen the results obtained. Future research could consider social and contextual factors such as class climate, teacher-student relations, peer relations in investigating the impact of ER on STEM engagement. For instance, future studies should consider peer, teachers support, and teaching style as possible moderators of the models tested. Moreover, future studies could implement robot-supported STEM activities for a period longer than 10 hours, as the relatively short duration of the activities could affect their impact on students.

A great deal of variability can be found in the literature, ranging from 80 minutes to 24 hours for robotics activities aiming to develop CT in formal education settings (Ching & Hsu, 2024). Moreover, no follow-up assessment was conducted, and no control group is included; future studies should incorporate a control group and delayed measures (e.g. 4 weeks post-intervention) to evaluate the persistence of effects detected and strengthen the obtained results. Finally, future research should investigate whether our preliminary results are replicated in countries with educational systems different from Italy, where the project-based approach to learning is more common.

6.2 Practical Implications

The present findings offer preliminary insights into how positive emotional engagement may function as a pathway through which robotic-based STEM activities become associated with students' task self-efficacy. From an applied perspective, practitioners implementing LEGO Spike Prime activities might attend to fostering and monitoring enjoyment during science lessons, given the observed associations between positive affect experienced in this domain and students' subsequent confidence in completing science tasks.

This consideration could inform the design of lesson sequences in which emotional engagement is treated as a deliberate pedagogical element rather than as incidental to task completion. Future work would benefit from clarifying the temporal dynamics of this association: longitudinal designs incorporating multiple measurement points could illuminate whether the link between enjoyment and self-efficacy consolidates, attenuates, or transforms over more extended engagement with robotic activities, thereby helping educators identify when affective scaffolding might be most usefully introduced.

The pattern of findings related to mBot, wherein students demonstrated higher post-activity task self-efficacy compared with their LEGO Spike counterparts, notwithstanding the absence of statistically significant pre-post changes, invites educators to reflect on how distinct robotic platforms may relate to learners' perceived competence. The relative accessibility of mBot tasks, or the nature of the competence-relevant feedback embedded in the platform's design, represents a plausible focus for further inquiry. Qualitative and mixed-methods research could accordingly help to elucidate which specific features of each platform, such as immediate visual feedback, task scaffolding, or aesthetic and ergonomic

design, may be associated with the differential patterns of emotional and efficacy-related outcomes observed here, providing a more granular basis for platform selection in classroom settings.

7. Conclusion

This study offers a preliminary contribution to understanding how two distinct robotic kits—LEGO Spike and mBot—may relate to junior high school students' enjoyment of lessons and their self-efficacy in approaching mathematics and science tasks. Engagement with LEGO Spike appeared to be accompanied by greater self-efficacy in science tasks alongside the enjoyment students experienced during science lessons, whereas mBot appears to be more closely linked with homework self-efficacy in a more immediate way in the math domain. These observations are best understood as describing how affective experience and perceived self-efficacy may move together in robotic-enhanced learning. In this sense, the study resonates with broader perspectives that view emotional engagement as interwoven with students' sense of competence, while making the comparatively novel move of placing two specific robotics kits side by side within a single design and in relation to two specific STEM domains (i.e., math and science).

Read with due caution, these insights may offer useful points of reflection for educators considering how the character of different kits might align with particular learning aims—for instance, where the priority is to nurture engagement as opposed to supporting task competence more directly. On a broader level, observations of this kind may gradually inform more considered decisions about technology adoption in schools, encouraging choices that are guided by pedagogical purpose rather than treating robotics kits as interchangeable tools. These are early indications rather than definitive conclusions, and call for further inquiry through larger, more structured and longitudinally designed studies, ideally enriched by qualitative exploration of what distinguishes one robotic activity from another, so that the potential expressed here can be examined more fully and translated into concrete guidance for practice and policy.

Conflict of Interest

None.

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