# Fostering Stem Literacy through Educational Robotics: An Experiential Learning via Stem Carnival

**Ong Sing Ling, Marcella Peter, Nur Atiqah Zaini, Khairunnisa Ibrahim and Jill Ling**


## Abstract

The integration of Educational Robotics (ER) in Science, Technology, Engineering and Mathematics (STEM) education has garnered attention for its positive impact on students' holistic learning experiences. However, the incorporation of "T" (Technology) discipline of STEM often face limitations due to financial constraints and resource scarcity. This study aimed to explore the potential of ER in fostering STEM literacy and soft skills among students, utilising a STEM Carnival as an engaging platform. The research was conducted at SMK Rosli Dhoby in Sibu, Malaysia, and involved students from Form 1 to Form 6 in the Malaysian secondary school. This research employed a quantitative approach using a questionnaire administered to one hundred fifty participants obtained through random sampling. The findings revealed a significant positive impact of ER on fostering STEM knowledge and 21st-century skills. A Chi-square test was employed to examine gender differences in prior exposure to robotics before the STEM Carnival, indicating a significant association with interest in Technology but not with Science and Mathematics. A majority of participants expressed a keen interest in exploring ER and engaging in STEM fields beyond the event. This study offers valuable insights for educators, policymakers and event organisers promoting STEM education through ER.


**Keywords:** Educational Robotics, Experiential Learning, Holistic Learning, STEM Carnival, STEM Literacy

## Introduction

Educational Robotics (ER) represents an evolving interdisciplinary learning environment based on the use of robots and electronic components. It harnesses experiential learning methodologies to enhance the educational experience with student engagement and fosters the development of STEM literacy and various soft skills towards holistic learning. Holistic learning refers to an educational approach that acknowledges the interconnectedness of numerous aspects of learning rather than focusing solely on individual subjects or isolated skills. It is relevant to ER, where holistic learning happens because the emphasis is on nurturing cognitive, emotional, social and physical abilities, and creativity.

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ER has gained considerable traction in research and education, with educators increasingly adopting robotics as a pedagogical tool to teach STEM subjects (Anwar et al., 2019; Sapounidis & Alimisis, 2020; Theodoropoulou et al., 2021). ER integrates education theories and robotics to offer students experiential learning experiences, utilising robots and related technology to convey concepts from various disciplines within engaging and interactive learning environments to simulate real-world challenges (Ching & Hsu, 2023). Experiential learning is an educational approach that focuses on learning through direct and hands-on experience rather than relying solely on traditional methods such as lectures or textbooks. Experiential learning in ER encourages learners to explore, reflect, and apply their knowledge in real-world situations characterised by hands-on activities, experiments, fieldwork and simulations that foster STEM literacy. STEM literacy refers to a person's ability to understand, engage with, and apply concepts from Science, Technology, Engineering, and Mathematics (STEM).

Over the years, ER has gained popularity for its role in cultivating the 4Cs: Critical thinking, Creativity, Communication and Collaboration among students. However, despite the growing interest and efforts in ER, its adoption can be hindered by cost disparities, which depend on factors such as the robotics type, complexity, and the resources required for effective implementation, guidance, and collaboration (Bers et al., 2019; Sapounidis & Alimisis, 2020; Wang et al., 2020).

This study aimed to address the challenges and explore the potential of ER in fostering STEM literacy through STEM Carnival. A STEM Carnival is an event with a variety of hands-on exhibits, interactive demonstrations, games, and activities that showcase the elements of Science, Technology, Engineering, and Mathematics (STEM) with the interactive atmosphere of a carnival to make STEM subjects engaging, entertaining, and accessible to the students and the public. Specifically, the study investigated the use of the STEM Carnival as an engaging platform for ER exploration. Additionally, it examined potential gender differences whether varying interests in Science, Mathematics, or Technology among genders impact this experience. Notably, this study responded to the common constraints encountered by schools in acquiring ER, thereby promoting holistic and experiential STEM education through STEM Carnival. Therefore, the research addressed the following questions:

1. How does Educational Robotics (ER) contribute to STEM literacy within the context of a STEM Carnival?
2. Are there gender-based disparities in the experiential learning experience when using ER?
3. Do differences in interests related to Science, Mathematics or Technology influence the experiential learning experience when using ER?

## Literature Review

The rise of Industrial Revolution 4.0 and the increasing reliance on the digital economy drive the need for a new set of skills, especially in robotics for the young generation (Adnan et al., 2023). Previous research has found that Educational Robotics (ER) facilitates students' cognitive learning of STEM knowledge, problem-solving skills, computational thinking and soft skills, such as teamwork and social skills, as well as affective domains including attitudes and interests towards STEM subjects and careers (Hudson et al., 2020; Ong & Ling, 2020). ER can serve as a promising approach to enable students to foster STEM literacy because learning becomes more interactive and hands-on (Bers et al., 2019; Ching et al., 2018).

The potential of ER for experiential learning involves active engagement through hands-on activities with problem or project-based learning that encompasses computational thinking (Ong et al., 2022). Students collaborate in designing, building, and programming robots to perform specific tasks, allowing them to apply theoretical knowledge in a tangible and meaningful way. These activities provide a platform for students to learn by doing, fostering creativity, innovation, and the essential teamwork and communication skills. The development of experiential learning methodologies is gaining attention due to their contributions to enhancing the quality of education by building competencies and values. The interdisciplinary nature of ER accommodates a coherent interactive design process that facilitates innovation and develops various skills by adopting experiential learning approaches (Abidin et al., 2021; Habib et al., 2021). ER emphasises the interconnectedness of disciplines, such as engineering, computer science, mathematics, and design. ER and cooperative learning are more effective in stimulating the interest and motivation of students (D'Amico et al., 2020).

According to a study by Kucuk & Sisman (2020), female students had significantly less desire and confidence to learn robotics than male students. However, there was no gender effect on computational thinking and teamwork. Despite the investment in STEM areas for ER as a way to intensify innovation and bring positive learning impact, STEM learning in schools appears to be struggling and inconvenient due to the high costs (Castro et al., 2018; Ong & Ling, 2020). Therefore, the accessibility of low-cost ER and other alternative robotics needs to be further explored.

# Methodology

### Robotics and Designs

The Sphero BB-8 robots and self-designed robotic cars were used for Educational Robotics (ER) activities during the STEM Carnival. The BB-8 droid, as seen in Star Wars movie, is a type of astromech droid. These BB-8 robots can be controlled using smartphones or tablets through apps or coding, enabling users to control their movement, sounds, and rotating heads. Six BB-8 units and six units of low-cost, self-designed robotic cars powered by the Arduino platform were brought to the STEM Carnival. Multiple robotic maps, with different paths and challenges, were created to enhance ER activities during the STEM Carnival. Participants were tasked with completing challenges and objectives through the exploration of ER. Participants were challenged to complete tasks and achieve the objectives set through the ER. Before engaging in the ER activities, the participants were briefed on the basic operations of BB-8 robots and robotic cars.

### Participants

The study focused on a sample of one hundred fifty secondary school students from SMK Rosli Dhoby in Sibu, Sarawak, Malaysia. The participants enrolled in Form 1 to Form 6 fell within the age range of 13 to 19 years old.

### Instrument

This study employed a quantitative approach, involving the administration of a questionnaire which was adapted from the BioRobotics Institute in Italy (Castro et al., 2018) to participants following their engagement in the ER exploration activities. Its purpose was to assess the outcomes of this innovative implementation of ER activities during the STEM Carnival. The questionnaire comprised five sections. Section A collected

the participants' demographic data. Sections B and C assessed students' exploration experiences from the BB-8 and robotic cars ER activities. These sections included seven items each, and participants rated their responses on a four-point scale (4 = Strongly Agree; 3 = Agree; 2 = Disagree; 1 = Strongly Disagree). Notably, a neutral category was deliberately omitted to encourage respondents to make either positive or negative evaluations. Section D consisted of four multiple-choice questions designed to gauge participants' awareness and knowledge of robotics. For example, "What is the function of a robotics processor?" (a) the heart and brain of the robot, (b) the process of reaching a solution, (c) the computer, or (d) the component of the robot responsible for executing the program. Section E encompassed three questions focused on participants' motivation in robotics.

# Results

A total of one hundred and fifty participants voluntarily completed the questionnaire. Descriptive statistics were employed to process the data, utilising IBM Statistical Package for Social Sciences (SPSS) software version 25. Cronbach's alpha coefficient was employed to determine the reliability of the questionnaire items within each construct. As a general guideline, a Cronbach's alpha value of 0.7 or higher is indicative of an acceptable level of reliability (Santos, 1999).

## Data Analysis

### *Descriptive Analysis*

The demographic data, encompassing gender, age, level of study, and race, were recorded and presented in Table 1. Regarding their interest in Science, 136 respondents (90.7%) indicated a positive interest, while 14 respondents (9.3%) expressed no interest. Surprisingly, only 85 respondents (56.7%) reported a liking for Mathematics, while 65 respondents (43.3%) expressed a dislike for the subject. A significant majority of the participants, totalling 133 individuals (88.7%), conveyed their fondness for technology, with 17 respondents (11.3%) indicating otherwise. In response to whether they had prior exposure to robotics before the STEM Carnival, 84 respondents (56%) affirmed their previous experience, while 66 respondents (44%) had not been previously exposed to robotics. Nearly all respondents, comprising 147 individuals (98%), expressed their enjoyment of the robotics activities when given the opportunity at the STEM Carnival.

In Table 2, the questionnaire items were coded into three categories: BB-8 Exploration Learning Experience (B), Robotic Car Exploration Learning Experience (C), and Motivation in Robotics (M). From the data analysis, it was found that a significant majority of the respondents either agreed (63.3%) or strongly agreed (32.7%) that they had successfully explored the operations and movements of the BB-8 robot using the Sphero BB-8 app. The respondents expressed high levels of enthusiasm and engagement with BB-8 robotics, with 39.3% in agreement and 58.7% strongly agreeing, as opposed to robotic cars, where 48% agreed and 50% strongly agreed. This observation indicated that a majority of the respondents exhibited a strong attraction to both. These findings aligned with the notion that the use of both BB-8 robotics (38% agreed and 60.6% strongly agreed) and robotic cars (41.3% agreed and 57.4% strongly agreed) was perceived as enjoyable and conducive to STEM learning.

**Table 1** Demographic analysis of respondents

| Characteristics | Categories | Frequency | Percentage (%) |
|---|---|---|---|
| Gender | Male | 75 | 50.0 |
| | Female | 75 | 50.0 |
| Age | 13 | 8 | 5.3 |
| | 14 | 45 | 30.0 |
| | 15 | 30 | 20.0 |
| | 16 | 26 | 17.3 |
| | 17 | 17 | 11.4 |
| | 18 and above | 24 | 16.0 |
| Level of study | Form 1 | 8 | 5.3 |
| | Form 2 | 48 | 32.0 |
| | Form 3 | 29 | 19.3 |
| | Form 4 | 25 | 16.7 |
| | Form 5 | 18 | 12.0 |
| | Form 6 | 22 | 14.7 |
| Race / Ethnic group | Malay | 34 | 22.7 |
| | Chinese | 17 | 11.3 |
| | Indian | 1 | 0.7 |
| | Iban | 65 | 43.3 |
| | Melanau | 22 | 14.7 |
| | Bidayuh | 5 | 3.3 |
| | Other | 6 | 4.0 |
| Do you like Science? | Yes | 136 | 90.7 |
| | No | 14 | 9.3 |
| Do you like Mathematics? | Yes | 85 | 56.7 |
| | No | 65 | 43.3 |
| Do you like Technology? | Yes | 133 | 88.7 |
| | No | 17 | 11.3 |
| Any exposure to robotics before this STEM Carnival? | Yes | 84 | 56.0 |
| | No | 66 | 44.0 |
| Do you enjoy playing with robotics if you are given the opportunity? | Yes | 147 | 98.0 |
| | No | 3 | 2.0 |

**Table 2** Items in the questionnaires

| Code | Items | 1 Strongly Disagree (%) | 2 Disagree (%) | 3 Agree (%) | 4 Strongly Agree (%) |
|---|---|---|---|---|---|
| | ***BB-8 Exploration Learning Experience (B)*** | | | | |
| B1 | BB-8 exploration during the STEM Carnival helps me in exploring the operations and movements of BB-8 via Sphero BB-8 app. | 2.0 | 2.0 | 63.3 | 32.7 |
| B2 | BB-8 exploration during the STEM Carnival gives me an awareness to the functions of BB-8 via the Sphero BB-8 app. | 1.3 | 8.0 | 60.0 | 30.7 |
| B3 | I am excited to see BB-8 robotics because it is attractive and engaging. | 0.0 | 2.0 | 39.3 | 58.7 |
| B4 | Learning BB-8 robotics is fun and happy. | 0.7 | 0.7 | 38.0 | 60.6 |
| B5 | I am curious about how BB-8 works. | 0.7 | 6.0 | 53.3 | 40.0 |
| B6 | I am interested to know the electronics components (e.g. sensor for detection, LED for lighting, buzzer for sound, motor for moving) of the BB-8. | 1.3 | 5.3 | 54.0 | 39.4 |
| B7 | The BB-8 robot triggers me to think and solve the challenges to reach a goal. | 0.7 | 2.0 | 49.3 | 48.0 |
| | ***Robotic Car Exploration Learning Experience (C)*** | | | | |
| C1 | Robotic car exploration during the STEM Carnival helps me in exploring the operations and movements of the robotic car. | 1.3 | 1.3 | 59.3 | 38.1 |
| C2 | Robotic car exploration during the STEM Carnival gives me an awareness of the functions of the robot car. | 0.0 | 8.6 | 58.7 | 32.7 |
| C3 | I am excited to see robotic car because it is attractive and engaging. | 0.7 | 1.3 | 48.0 | 50.0 |
| C4 | Learning robotic car is fun and happy. | 0.0 | 1.3 | 41.3 | 57.4 |
| C5 | I am curious about how robotic car works. | 1.3 | 5.3 | 43.3 | 50.1 |
| C6 | I am interested to know the electronics components (e.g., sensor for detection, LED for lighting, buzzer for sound, motor for movement) of the robotic car. | 0.7 | 5.3 | 51.3 | 42.7 |
| C7 | The robotic car triggers me to think and solve the challenges to reach a goal. | 0.7 | 0.7 | 50.6 | 48.0 |
| | ***Motivation in Robotics (M)*** | | | | |
| M1 | I would be eager to learn more with robotics, for example, coding with robotics. | 0.7 | 2.0 | 56.0 | 41.3 |
| M2 | I would be eager to assemble a robot. | 2.7 | 4.0 | 70.0 | 23.3 |
| M3 | Learning robotics motivates me to continue my studies in STEM programmes, such as Computer Science, Electronic Engineering or technology-related programmes. | 0.7 | 1.3 | 57.3 | 40.7 |

A striking 97.3% of the respondents either agreed (49.3%) or strongly agreed (48%) that they were prompted to engage in critical thinking and problem-solving as they navigated the challenges presented with BB-8 robotics to achieve their objectives. In contrast, when employing robotic cars as a tool, 50.6% agreed, and an additional 48% strongly agreed with this approach to engage their analytical and problem-solving skills. A majority of respondents, comprising 43.3% who agreed and 50.1% who strongly agreed, expressed their curiosity about the inner workings of the robotic car. Furthermore, a substantial 94% of respondents, with 51.3% in agreement and 42.7% strongly agreeing, conveyed their keen interest in understanding the electronic components (e.g., sensors for detection, LEDs for lighting, buzzers for sound, motors for movement) used in the robotic car.

The findings highlighted the beneficial influence of robotics in cultivating STEM literacy among students. The students exhibited a strong enthusiasm for deepening their understanding of robotics, encompassing coding and assembly aspects. Remarkably, an overwhelming 98% of the respondents either agreed (57.3%) or strongly agreed (40.7%) that their experience in learning robotics served as a motivation to pursue future studies in STEM programmes, including Computer Science, Electronic Engineering, Mechanical Engineering, or other technology-related fields.

The results from the Chi-square test revealed several insights. Firstly, there was no statistically significant association between gender and prior exposure to robotics before the STEM Carnival, as evidenced by a p-value of 0.0908, which was greater than the conventional significance level of 0.05. Secondly, the examination of whether a significant association existed between gender and interest in Science impacting ER exploration yielded a p-value of 0.102, also exceeding the significance threshold. Consequently, no significant association was found between gender and interest in Science concerning ER exploration. Similarly, when investigating the association between gender and interest in Mathematics affecting ER exploration, the p-value obtained was 0.250, which indicated the absence of a significant association. However, the analysis took a different turn when probing the relationship between gender and interest in technology during ER exploration. In this case, the p-value was 0.000, which was less than the threshold, revealing a significant association between interest in technology and gender.

### *Reliability Analysis*

A reliability analysis using Cronbach's Alpha was conducted and the results are presented in Table 3. It is noteworthy that all the constructs achieved a minimum Cronbach's Alpha value of 0.700, indicating that the data's reliability can be deemed satisfactory.

**Table 3** Cronbach alpha

| Construct | Alpha |
|---|---|
| BB-8 Exploration (B) | .835 |
| Robotic Car Exploration (C) | .889 |
| Motivation in Robotics (M) | .718 |

## Discussion

Despite some limitations, the introduction of Educational Robotics (ER) through the STEM Carnival platform emerges as a viable solution to schools. This approach effectively exposes students to robotics and fosters STEM literacy through experiential learning. The STEM Carnival featured interactive exhibits and hands-on activities centered on ER, offering participant's valuable opportunities to actively engage with the 4Cs: Collaboration, Communication, Critical thinking and Creativity. This not only enhances students' understanding of robotics but also promotes the development of problem-solving skills. These findings align with the research by Theodoropoulou et al., 2021, which suggested that ER plays a vital role in nurturing 21st-century skills and can be effectively integrated into teaching various subjects across different educational levels. Furthermore, the study echoes the effectiveness of ER in providing impactful learning experiences, enhancing students' learning and transfer skills, fostering creativity and motivation, and promoting diversity and broader participation, as documented by Anwar et al. (2019).

The findings from this study revealed that factors such as prior exposure to robotics, interests in Science and Mathematics, as well as gender, did not significantly impact ER learning. In contrast, a strong interest in Technology emerges as a key influencer in ER exploration. This suggests that possessing a proclivity for technology provides an advantage in mastering ER concepts and applications. ER plays a pivotal role in stimulating curiosity, deepening students' comprehension of STEM concepts, and bolstering their motivation to engage in STEM learning. Moreover, the collaborative nature of ER activities fosters the development of teamwork and communication skills, aligned with the insights offered by Eguchi (2014).

Learning through ER entails a holistic understanding of interconnected disciplines combined with hands-on experiential learning. This approach cultivates a profound comprehension of robotics concepts and equips students with practical skills essential for navigating the ever-evolving technological landscape. Students are encouraged to delve into the foundational principles underpinning robotic systems, enabling them to perceive the larger framework and recognise the intricate interplay among different components. This comprehensive perspective contributes to a deeper understanding of robotics, thereby promoting critical thinking and problem-solving skills, as emphasised by Ching et al. (2019). The engagement of students in hands-on learning scenarios can significantly ignite their STEM interest and literacy. Figures 1 and 2 show the visual representation of the BB-8 robotics and robotic cars exploration activities conducted during the STEM Carnival.



**Figure 1.** BB-8 Robotics Exploration.

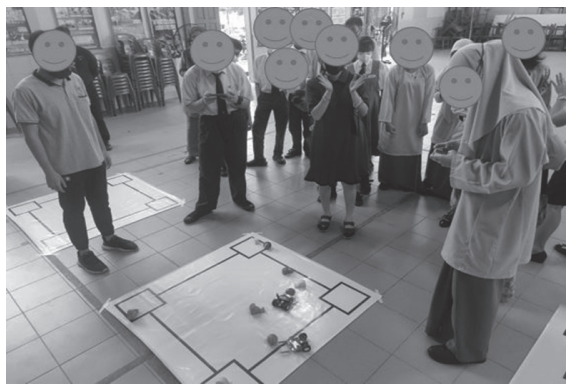


**Figure 2.** Robotic Cars Exploration.

## Conclusions

In conclusion, this study addressed three objectives: to explore ER's potential in fostering STEM literacy while stimulating students' awareness and curiosity through STEM Carnival interventions, to examine gender differences in ER learning experiences, and to understand how students' interests in various subjects impact the ER learning process. Acknowledging the financial and resource constraints faced by schools, this study proposed the utilisation of a STEM Carnival as a practical and effective platform for introducing ER. The findings confirm that ER has potential for fostering STEM literacy and enhancing soft skills among students. Furthermore, it has been established that there was no significant association between gender and prior exposure to robotics or interests in Science and Mathematics in ER exploration. However, a significant association was observed between interest in Technology and gender. These insights underline the ER's effectiveness as an educational tool in stimulating students' interest in STEM subjects and promoting valuable 21st-century skills.

It is recommended to conduct experimental studies during STEM Carnivals utilising pre- and post-tests to assess the improvement in ER exploration among students comprehensively. In addition, investigating students' perceptions of their learning experiences, including the challenges and benefits of collaborative work and the use of various ER platforms, could yield valuable insights. Addressing observations and feedback from participants would further enrich future research. Moreover, future studies may benefit from adopting longitudinal designs to investigate the long-term effects of ER learning approaches on students' learning outcomes and attitudes. This would provide a more in-depth understanding of the sustained impact of ER.

ER emerges as an innovative learning method well-suited for self-directed learners who exhibit flexibility in their knowledge acquisition. They thrive in adaptable learning environments, employ critical thinking, and excel in learning through exploration. The insights gleaned from this study can serve as a valuable resource for educators and policymakers alike when designing and implementing relevant courses and initiatives. By harnessing the power of ER, educators can cater to the needs of a diverse range of learners and foster a deeper engagement with STEM subjects, ultimately paving the way for a brighter future in education.

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