THE EFFECT OF EDUCATIONAL ROBOTS ON PRIMARY SCHOOLS' MATHEMATICS LEARNING ACHIEVEMENT, INTEREST, AND ATTITUDE

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ABSTRACT

Educational robotics (ER) is a constructivist approach to education that promotes experiential learning through actual activities for teaching and learning science, technology, engineering, and mathematics (STEM) subjects. Empirical findings have indicated that primary school students have limited interest in learning mathematics due to the inability to rationalize real-world applications without practical application. Therefore, this study aims to determine the implications of using ER to evaluate their effect on primary school students' mathematics learning achievement, interest, and attitude. A total of 40 respondents from year five participated in this quasi-experimental study that explored the difference between using ER and PowerPoint hands-on methods as instructional approaches to complement teaching and learning. The findings indicated that ER improved mathematics learning achievement and perceived interest with a high effect size, and students also indicated a positive attitude toward using ER to aid in learning mathematics.

Keywords: *educational robots, Rero-Micro, mathematics education, primary mathematics, interest, achievement*

INTRODUCTION

Integrating technologies in teaching and learning has become a fundamental need to promote science, technology, engineering, and mathematics (STEM) education in schools (Adnan et al., 2022; Gillen & Kucirkova, 2018). Likewise, teaching and learning should align with technological changes, especially state-of-the-art computer applications, to facilitate and adapt to the current needs of the generation (Crittenden et al., 2019). One such tool is the application of robots for pedagogical purposes (Chahine et al., 2020; Negrini & Giang, 2019), defined as educational robotics (ER) (Tselegkaridis & Sapounidis, 2021). According to Todorovska and Bogdanova (2020), implementing ER in early childhood offers many opportunities that could be used to innovate twenty-first century classrooms. Tzagkaraki et al. (2021) assert that ER is a pedagogical tool that may provide a different take on traditional STEM subjects while initiating programming and problem-solving skills that also focuses on learning discovery and "trial and error." Additionally, such programming skills enhance students' visualization of learning (Hsiao et al., 2022) and enable them to correlate new and past knowledge (Sharma et al., 2019). Davison et al. (2020) explain that teaching and learning using robotics facilitates interaction that triggers the cognitive learning processes that simultaneously promote critical and creative thinking while supporting problem-solving competencies.

In the same way, ER in general could play an active role in mathematics education (Zhong & Xia, 2020). Mathematics is a subject that requires an understanding of how to quantify numbers through reasoning and analytical skills and is essential in solving day-to-day problems or challenging conditions in numerous fields (Aliyu et al., 2021). According to Ying et al. (2020), mathematical skills must be mastered in the formative years, as they may influence problem-solving skills and interest in STEM areas. However, mathematics is often considered complex (Widakdo, 2017) where students find it difficult to relate the theoretical aspects learned in mathematics to solve real issues (Adnan et al., 2022; Nurhayani et al., 2020). Similarly, this was also observed in Malaysian primary schools (Ying et al., 2020), where students also portray disinterest in mathematics (Mazana et al., 2018). Mathematics education in Malaysia often focuses on learning numbers, arithmetic, and the relationships between the numerals (Ganesen et al., 2020) and lacks strategies that enable students to reflect and apply mathematical knowledge and understanding using tangible applications (Saundarajan et al., 2020). While it is essential to consider various teaching and learning techniques, students' abilities, experiences, and interests (Lai, 2018), Olsen (2020) and Saundarajan et al. (2020) suggest using educational technologies as a means to facilitate mathematics comprehension and problem-solving skills. Accordingly, Adnan et al. (2022) claim that due to the association between mathematics achievements and STEM interests, integrating technology-assisted mathematics instruction could be a viable resource to improve mathematical knowledge in the classroom.

Consequently, Lopez-Caudana et al. (2020) claim that ER in primary mathematics education could provide a positive outcome as ER aids in improving attention and motivation while developing a positive learning community, especially between teacher and student. However, few studies have considered ER in primary schools (Greca Dufranc et al., 2020), and such could also be observed in Malaysia (Zaharin et al., 2019). Empirical findings claimed challenges in such integration due to a lack of strategies for integrating STEM in Malaysian primary schools (Balakrishnan et al., 2021) and how ER could facilitate such integration (Muniandy et al., 2022). Nevertheless, ER in primary schools can nurture students' positive interests and attitudes toward STEM subjects and choices of future careers (Roberts et al., 2018). Likewise, there is also a need to investigate perceived interest in STEM to fully understand the implications of ER (Tengler et al., 2021; Todorovska & Bogdanova, 2020), especially by considering students' perspectives (Negrini & Giang, 2019). Therefore, this study investigates if ER used to complement the teaching and learning of mathematics could improve student achievement and interest in mathematics. Hence, ER instructional strategies will be compared to traditional strategies using PowerPoint and hands-on activity (PH) as a control group to evaluate these outcomes. Additionally, this study also aims to investigate students' perceived attitudes toward using ER for learning mathematics by answering the following research questions:

1. Is there a significant difference between ER and PH instructional strategies toward student achievement and interest in learning mathematics?
2. How do students perceive their attitudes toward using ER for learning mathematics?

LITERATURE REVIEW

Educational Robots

Robotics in education, often known as educational robotics, is the term used to describe robot-assisted teaching (Thomaz et al., 2009) and has been deemed a valuable resource for developing STEM activities (Valsamidis et al., 2021). It was developed by considering the fields of robotics by focusing on the work of Seymour Papert, education based on Lev Vygotsky, and children learning psychology by Jean Piaget to create meaningful experiences in early childhood (Scaradozzi et al., 2019). The underlying theory focuses on a constructivist approach, where a hands-on approach to creating and handling physical objects plays a significant role in children's learning processes (Hong et al., 2020). Henceforth, ER has become prevalent in many levels of education (Crnokić et al., 2017; Patiño-Escarcina et al., 2021), including primary schools, as it fosters the playful aspect in individuals that can stimulate the development of various skills and abilities (Sullivan & Bers, 2017).

Moreover, empirical evidence suggests that ER has a favorable influence on children (Sapounidis & Alimisis, 2021) and is especially important in early schooling since they are analogous to the traditional concepts of learning with toys (Strawhacker & Bers, 2015), focusing on play (Paaskesen, 2020). Furthermore, ER as a STEM tool can engage and be used to explain complex topics that spark children's imaginations (Isnaini & Budiyanto, 2018). Likewise, the physical representation of ER is considered more advantageous than other frequently used teaching strategies as it also aids in students' engagement, which may influence their interest (Papadakis et al., 2021).

Educational Robot in Malaysia

According to Jiea et al. (2018), ER is capable of aligning with the ever-demanding need to apply the Internet of Things (IoT) concept in the classroom. In parallel, ER has shown promising results as an effective tool for efficiently learning the concepts and principles of mathematics (Estivill-Castro, 2020). Thus, the Malaysian Ministry of Education, considering these advantages and how it may positively impact STEM education (Nashir et al., 2019), strategized workshops to equip teachers with the necessary skills to implement robotics for teaching and learning (Ling et al., 2019).

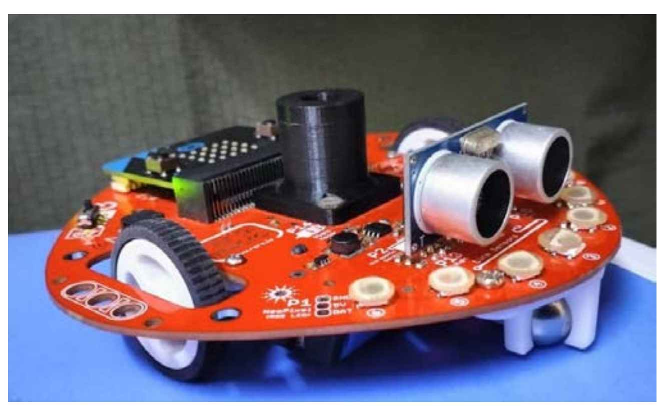
However, there are a few ER types available for teaching and learning, such as Android, zoomorphic, mobile, poly-articulated, and hybrid (Pachidis et al., 2019). Androids are defined as robots that appear with human characteristics; zoomorphic with animal characteristics; mobile ER as robots with capabilities to move with wheels; poly-articulated as robots with a tendency to move objects, such as a robotic arm; and hybrid ER, which is a mixture of all the other categories (Johal, 2020; Papadakis, 2020). According to Iberdrola (2023), mobile-based ER is the most appropriate for primary education, as it also emphasizes the construction of the robot that may facilitate the constructivist learning approach. Mobile ER examples used to date are such as the LEGO Mindstorms NXT, Darwin-OP (Crnokić et al., 2017), EvaMars, EvaSec, ATEKS, and AGV-OTA (Erdoğmuş & Yayan, 2021). However, in this study, we utilized a locally made ER named Rero-Micro. The Rero-Micro robot is an educational robot introduced in primary schools in Malaysia and reflected to be in line with the Malaysian National Educational Blueprint.

Rero-Micro

Rero-Micro is an educational robotic kit developed by Cytron Technologies based in Malaysia (Figure 1). It allows the integration and manipulation of videos, audio, graphics, and animation and is an excellent learning tool that incorporates the benefits of educational media. Rero-Micro is a fully assembled robot with built-in line sensors that enable the robot to perform numerous tasks, such as drawing lines and shapes, moving along the line, and turning at the desired angle. It also contains a 12C interface port (multiple ICs on the same circuit board), which allows adding any 12C sensors, such as distance, color, temperature, humidity, LCD/OLED modules, and PWM/Analogue/IO Expansion module. This robot can be coded using the https://makecode.microbit.org platform, developed by the Microsoft MakeCode initiative.

Moreover, the robot was designed to be kid-friendly and has been used by the Malaysian Ministry of Education and other government bodies to promote programming skills. Empirical findings of using the Rero-Micro as a learning aid for mathematics have indicated a positive attitude as students were found to have more confidence in their ability to solve complex problems (Kucuk & Sisman, 2017). Furthermore, it has been found to motivate learners by providing hands-on application to a mathematical problem (Zhong & Xia, 2020). However, to our knowledge, no such studies have been conducted in the Malaysian context.

Figure 1.
Rero-Micro Educational Robot



PROBLEM-BASED LEARNING

According to Barrows and Tamblyn (1980), problem-based learning (PBL) is a student-centered instructional strategy that emphasizes developing problem-solving, creativity, and critical thinking skills. Tan (2003) described PBL as a strategy that could be used as a foundation to develop the active learning process where a problem becomes the main objective of the lesson, from which all the students' planning, strategies, and work are driven toward finding a solution for the problems. Problem-based learning provides students with authentic and relevant situational problems that can allow them to investigate and apply inquiry learning (Umanailo et al., 2019) solidarity and the law. Additionally, PBL has been found to be an effective strategy for teaching and learning mathematics, even in the primary school environment (Aliyu et al., 2021)

Problem-Based Learning in Mathematics Education

According to Sari et al. (2018), mathematics education often requires real-life problem-solving skills, and PBL could be strategized to enable students to relate what they learn in the classroom to the real world. Empirical evidence in primary education indicated that PBL improves students' interest and enjoyment (LaForce et al., 2017) while developing their creativity, critical thinking, problem-solving, and self-directed learning skills in mathematics education (Ertmer et al., 2014). According to Aliyu et al. (2023), the PBL approach of active learning could focus on principles, applications, or methodologies vital to mathematics education. Additionally, empirical findings indicated that students are less likely to drop mathematics subjects when participating in PBL practices (Bicer & Lee, 2019) and are more optimistic about choosing STEM-related careers (Berk et al., 2014)technology, engineering, and mathematics (STEM. Likewise, the integration of PBL in mathematics education also facilitates twenty-first century learning strategies (Hakim et al., 2019), and such a combination, when applied with active learning strategies, often signifies positive outcomes (Conde et al., 2021).

Problem-Based Learning in Educational Robotics

The PBL approach, when used for ER, is aimed at promoting the constructionist learning approach through the physical manipulation of artifacts, which is supposed to foster the creation of mental representations of the world around them (Papert, 1980). Conversely, PBL-based tasks enable students to create, assess, and update concepts while programming robot interactions that necessitate children to explore, observe, reflect, and manipulate the behavior of the robotics to deliver an answer to the proposed problem (Chiazzese et al., 2019). Hence, embedding the concept of PBL with ER could further enhance students' understanding of mathematical concepts (Parno et al., 2019) through an authentic experience that aids in developing problem-solving skills (Gürses et al., 2007) by facilitating a hands-on, minds-on, and self-directed learning approach (Williams et al., 2007). In addition, such activities provide opportunities for students to become more closely engaged with their learning activity, which seems impossible in traditional environments due to time limitations (Büyükdede & Tanel, 2019). Hence, ER could be a vital resource used to help solve inattention in learning among children (Patiño-Escarcina et al., 2021).

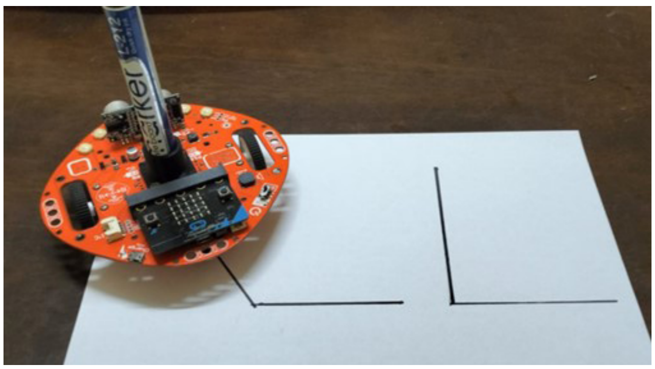
METHODOLOGY

Respondent and Learning Contents

Forty year-five students, aged 11, were recruited from a primary school in northern Malaysia for this study. The respondents from an intact class were divided into two groups: Group A (n = 20), defined as the treatment group, and Group B (n = 20) as the control group. The grouping was done without pre-assessing students' mathematics abilities, and students were randomly assigned to a group. Next, the content used for this study focuses on the topic "lines & angles" based on the Standard Curriculum Document for Year 5 (Kementerian Pendidikan Malaysia (2018). The objective of the contents is to recognize right angles, acute angles, and obtuse angles by matching the angles accurately. According to Martín-Ramos et al. (2017), using localized learning content aid students' visualization to use robots and improves their attitude toward mathematics.

According to Haryanti et al. (2019), primary students often face problems comprehending basic math skills, such as lines and angles, due to challenges in visualizing the content. Therefore, for Group A we utilized the content provided by Rero-Micro's curriculum as it was developed based on the Malaysian Primary School's Standard Curriculum for Mathematics, Science, and ICT subjects. Henceforth, based on the ten lessons provided in the Rero-Micro syllabus on their website (https://www.intelek.edu.my/product/reromicro-coding-robot-incl-microbit), we selected Lesson 4, titled "Let's Move It, Move It," for learning lines and angles. The lesson aims to program the robot to move and turn based on given angles (Figure 2). On the contrary, the control group (Group B) lessons were designed based on the lecture method, where PowerPoint slides were used as a teaching aid, followed by hands-on activity.

Figure 2.
Movement of Rero-Micro Robot



Instrument and Data Collection

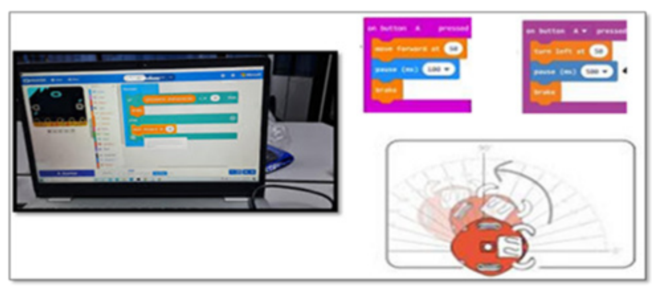
First, students' comprehension of the topic was measured using an assessment consisting of 20 subjective questions about identifying, naming, and calculating the angles. The pretest was administered after the traditional class for both groups, and all questions and rubrics were adapted from the school's question bank as the questions were previously validated per the curriculum requirement. The same questions were used for the pretest and post-test; examples are shown in Appendix A.

Next, perceived interest in learning mathematics was adapted from Frenzel et al. (2012) as the instrument focused on interest in mathematics for younger students. Frenzel et al. (2012) claim that adolescents' interest in mathematics is usually associated with emotional responses, while older students tend to relate cognitively. Therefore, the six-item questionnaire was adapted to project interest with statements like "I am interested in mathematics" and "I like solving mathematic problems" using a four-point Likert scale (1 = strongly disagree, 2 = Disagree, 3 = Agree, 4 = strongly agree), as suggested by Bell (2007). We also investigated the students' attitudes towards using ER by adapting the instrument by Abioye et al. (2017) for learning mathematics, where all assessment was done using a paper-based method. Moreover, before the investigation we obtained approval from the school and enlisted two teachers to aid in conducting this study. On the other hand, permission was also obtained from the parents, who were asked to sign an informed consent form explaining the study procedure and measures.

Research Design and Procedure

This study was quasi-experimental, where students were assigned to their groups using the randomization RAND function in Excel. First, the pretest scores for achievement and perceived interest were collected to obtain measures of the similarities between both groups. Next, before the intervention, all students were exposed to the topics using traditional "chalk-and-talk" teaching methods. After the two-week lesson, both groups were given pretest questions to determine their comprehension and perceived interest in learning mathematics. Next, all students were taught basic block programming skills for three weeks to ensure they were familiar with the ER coding platforms (Figure 3) and were exposed to Rero-Micro.

Figure 3.
Coding for Robot Movement



In the fourth week, Group A students were situated in a computer laboratory (Figure 4), while Group B students were placed in a classroom (Figure 5). Group A students were given three tasks to program in which they were required to move their robot based on the curriculum for Lesson 4 (Appendix B). After completing each task, students were required to display the outcome to their teacher and, in return, the teacher would give a token to perform the next task. Conversely for Group B, the class was conducted where the teacher showed examples using PowerPoint slides and provided hands-on classroom activities. The hands-on activities provide the opportunity to handle real objects and to perceive the sense of touch, which may help the students to acquire more knowledge (Klopp et al., 2014). Therefore, students draw angles using compasses and protractors following teachers' instructions. At the end of the sessions, students were given the perceived interest in mathematics questionnaire, followed by the achievement post-test. As for Group A, an additional questionnaire was given to measure students' attitudes toward mathematics.

Figure 4.
Group A in the Computer Lab

Figure 5.
Group B in the Classroom

Next, the data collected were digitally coded in Microsoft Excel for data matching and cleaning. The data, which were raw scores for both groups, were exported to the IBM Statistical Package for the Social Sciences (SPSS) for descriptive and inferential analysis. The Mann-Whitney U tests were used to analyze the differences between both groups, as the data were deemed not normally distributed.

RESULTS

The respondents were all 11 years old and the gender distribution of the class was 55% (n = 22) boys and 45% (n = 18) girls. First, it was observed that student comprehension (Table 1) prior to the intervention was not significantly different based on the Mann-Whitney U test (U = 170, p = 0.42) for Group A (M = 47.47, SD = 9.18) and Group B (M = 49.71, SD = 9.04), which reflect the homogeneity of the sample. Subsequently, based on the post-test results, Group A (M = 69.74, SD = 9.11) performed better than Group B (M = 52.93, SD = 12.95), and the Mann-Whitney U test showed that there was a significant difference (U = 63.5, p = 0.01) between both groups. The effect size calculated indicated Cohen's *d* value of 1.438, which implies a large effect. According to Cohen's classification of effect sizes, 0.1 is considered a small effect, 0.3 is a moderate effect, and 0.5 and above is a large effect (Cohen, 1988), which reflects that the ER experience significantly improved learning comprehension.

Table 1.
The Pretest and Post-Test Achievement Scores

The Pretest Score				The Post-Test Score			
Group A		Group B		Group A		Group B	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
47.47	9.18	49.71	9.04	69.74	9.11	52.93	12.95

Next, for perceived interest, during the pretest assessment, Group A (M = 2.53, SD = 0.79) reflected almost similar interest as Group B (M = 2.58, SD = 0.87), and the Mann-Whitney U test (U = 191.50, p = 0.817) conducted reflected no significant difference between both groups. Subsequently, based on after-treatment results, Group A (M = 3.53, SD = 0.49) showed more significant interest than Group B (M = 2.99, SD = 0.75), and the Mann-Whitney test indicates U = 106.50, p = 0.01. The mean rank value for Group A was determined to be significantly higher at 25.18, as opposed to Group B at 15.83 with an effect size of d = 0.87.

The attitude toward robotics questionnaire was only distributed to Group A, and the findings

(Table 2) indicate an overall positive attitude (M = 3.38, SD = 0.69). Students indicated the highest acceptance for the statement “I like learning mathematics using robots” (M = 3.65, SD = 0.67), followed by “Robots are amazing for learning mathematics” (M = 3.55, SD = 0.69). However, for the statement “I enjoy interacting with robots,” the mean value was the lowest (M = 3.10, SD = 1.07) but still indicated a positive attitude.

Table 2.
The Mean Score for Attitude Toward ER

No.	Item	Mean	SD
1	Robots are amazing for learning mathematics.	3.55	0.69
2	I am interested in using robot for learning mathematics.	3.35	0.75
3	I believe using robots can help me improve my understanding in mathematics.	3.25	0.91
4	I enjoy interacting with robots.	3.10	1.07
5	I like learning mathematics using robots.	3.65	0.67
Average Score		3.38	0.82

DISCUSSION AND CONCLUSIONS

The outcome of the findings indicates that the integration of ER to complement teaching and learning mathematics could positively impact learning outcomes. Firstly, a significant difference in student achievement was observed between both groups post-intervention, where students in Group A performed better than the control group with a high effect size (d = 1.438). Nevertheless, both groups showed improvement compared to their pretest results, and we theorized that this could be due to the problem-based activities introduced in both groups for the last session. Nevertheless, the manipulation of ER, which required programming and reasoning skills, undoubtedly reflected significantly better achievement. Hence, while literature in this context emphasizes real-world application to ensure positive learning outcomes (Aliyu et al., 2023; Conde et al., 2021; LaForce et al., 2017) and we orchestrated it through Group B’s intervention, it was observed that technology aspect and “play” are important aspects to consider. Conversely, the outcome of this study also supports the findings by Bray and Tangney (2017), claiming that technological tools help students find new pathways to support their learning; moreover, ER is such a tool in mathematics education, as Parno et al. (2019) report. Besides, Chiazzese et al. (2019) also report that the technological tool’s intervention highly impacts students’ achievement compared to traditional learning, which has also been observed in the case of ER in primary schools and as reported in this study.

Next, even though both groups reflected an improvement in perceived learning interest, it is reasonable to say that the robot-based activity provided the experience of hands-on technology practice, which was reflected as higher interest by Group A, and also reported by Chien and Chu (2018). Group A (ER) showed higher interest in learning mathematics compared to Group B (PowerPoint), with a high effect size (d = 0.87). Furthermore, this study reflects manipulation in both scenarios where the findings indicated that technology-based manipulation, as reflected through ER, improves learning interest compared to physical manipulation of objects performed using compasses and protractors. Beilock and Maloney (2015) also indicated that interactive learning, as we observed through the ER coding platform, helped students reduce their math anxiety, which we also stipulate could be related to the overall positive attitude observed. Conducting hands-on activities or task-oriented activities, which is typical for PBL (Chiazzese et al., 2019), such as controlling a robot, enhanced their interest and attitude, which is similar to the results of previous studies (Jose et al., 2017; Wang et al., 2018; Ziaeefard et al., 2016).

Therefore, engaging in innovative activities that are technology-based, such as robotics, improves the construction of knowledge and interest compared to traditional methods. Likewise, children can develop computational thinking skills through age-appropriate robotics kits and promising instructional approaches, which is essential for STEM subjects (Ching & Hsu, 2021). Integrating technology and engineering elements such as ER in mathematics aligns with Levenberg (2015), who states that interdisciplinary teaching saves time and adds a broader view that develops several skills together. Furthermore, we also observed that "play" is a vital part of learning mathematics for children, and strategies should be designed for this purpose and not solely on PBL and active learning. So, we can conclude that there is a significant difference in students' interest and performance in mathematics, and primary school students have a positive attitude towards using ER for learning mathematics.

Limitation and Future Direction

This study is limited to a group of year-five students at a primary school in the northern region of Malaysia, and for one subtopic; therefore, the outcome of this study cannot be generalized. However, future studies may consider different populations and topics that also consider different levels of complexity. It is also vital to align ER contents to current practices in the educational context by considering ER technologies when developing learning objectives, enrichment activities, and problem-solving tasks. Conversely, ER for children requires a "community" approach, as suggested by Gillen and Kucirkova (2018). Thus, future studies should also consider the role of each stakeholder, namely parents, teachers, and school administrators (Hall-Lay, 2018), to ensure the successful implementation of ER at the primary school level. Furthermore, it will also be interesting to evaluate how different modes of learning may impact ER education for primary school mathematics teaching and learning. Learning strategies such as asynchronous, synchronous learning, and AR/VR simulations are constantly evolving, and by considering various forms of blended learning approaches, alignment could be established to cater to how children learn today.

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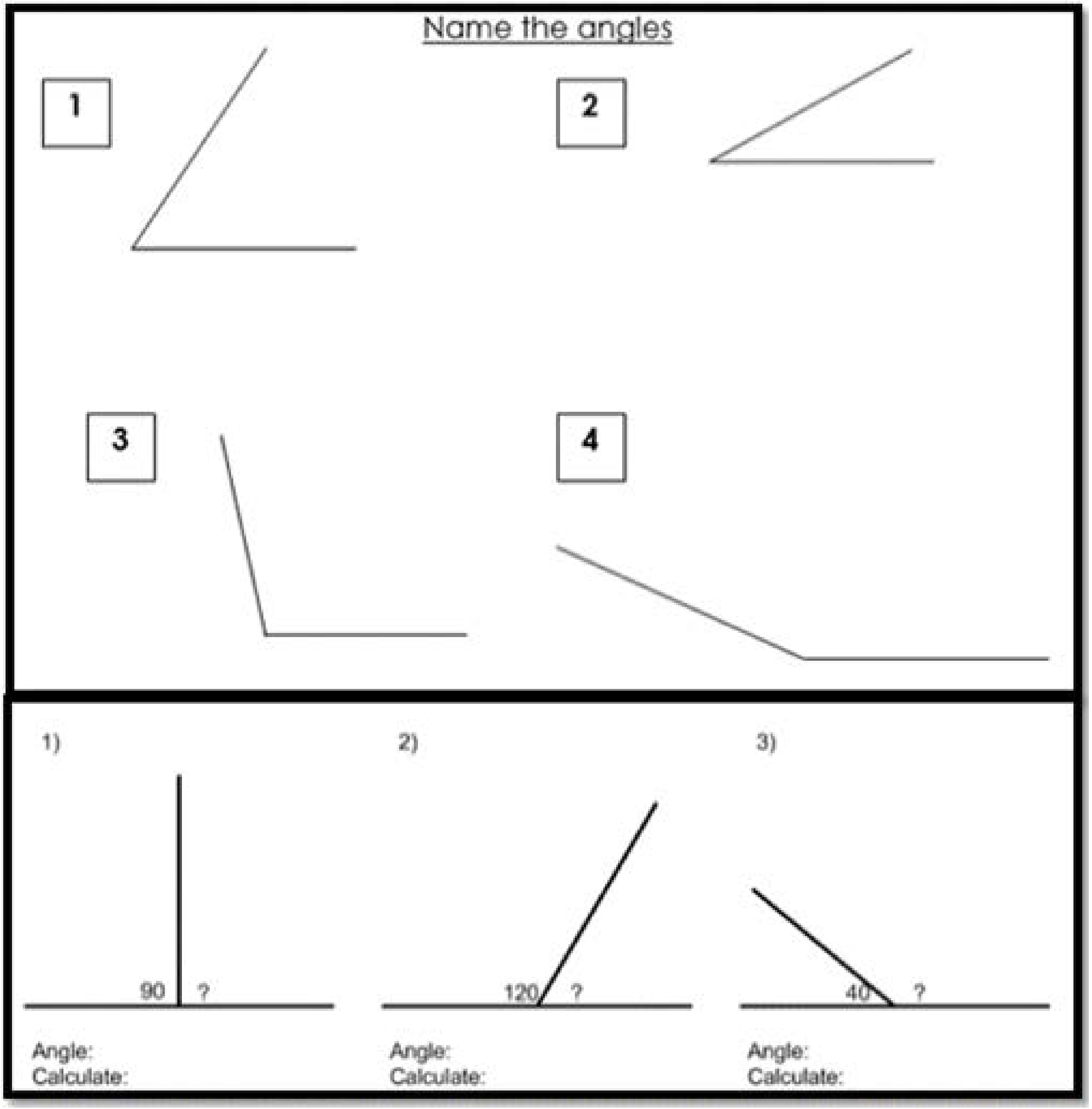
APPENDIX A



Name the angles
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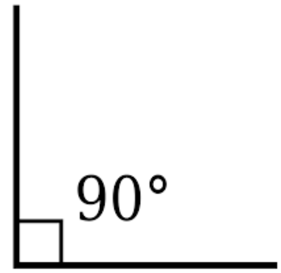
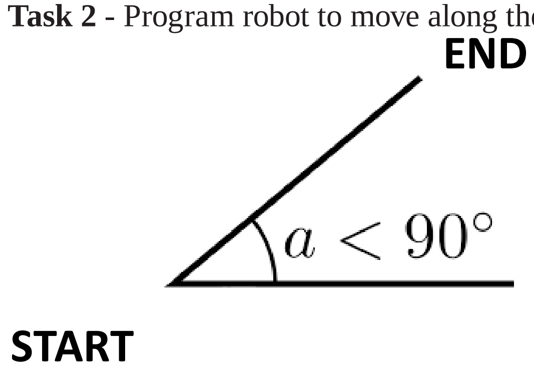
APPENDIX B

(i) **Task 1** - Program robot to move along the right angular line



(ii) **Task 2** - Program robot to move along the acute angular line



(iii) **Task 3** - Program robot to move along the obtuse angular line