Impact of Using an Educational Robot-Based Learning System on Students' Motivation in Elementary Education

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Abstract—Educational robotics has been regarded as an effective instructional tool over the past decade. Many studies have tested the role of robots in supporting educational classroom activities. However, reliable empirical evidence confirming the effectiveness of educational robots remains limited. Therefore, this study developed an educational robot-based learning system that provides an attractive teaching application that combines multimedia objects with an educational robot. This study examined the impact of the proposed learning system on student learning performance and motivation. The four-stage experimental procedure involved a pre-test, post-test, learning activities, and questionnaire survey. The participants comprised one homeroom teacher and 52 second-grade students from two classes at an elementary school in Taiwan. All of the students were assigned to use either the proposed learning system or a PowerPoint-based learning system. The pre-test and post-test results show that the proposed learning system improved student performance more than the PowerPoint-based learning system did. A questionnaire based on the Instructional Materials Motivation Survey (IMMS) was employed to measure four motivational factors (attention, relevance, confidence, and satisfaction). The IMMS survey results show that satisfaction and relevance were the highest rated motivational factors among students who used the proposed learning system. The experimental results indicate that the students were motivated to use the educational robot-based learning system. Thus, using educational robot-based learning systems in classrooms demonstrates a significant advantage for students, by improving overall learning interest and motivation.

Index Terms—Commercial robots and applications, computer-assisted instruction, educational technology, student motivation

1 Introduction

Using robotics to support various applications has become considerably more prevalent during the past decade. In particular, employing robotics in an educational context has become a widely researched topic [1], [2], [3], [4]. Most robots examined in previous studies involve using a tangible user interface and an anthropomorphic robotics body that attracts users' attention and facilitates socially meaningful interactions [5], [6]. Numerous studies have concluded that the actions of robots leave strong impressions on users [7], [8], [9], [10]. Shinozawa et al. [11] asserted that a robot's motions and body gestures can provide strong motivators that affect user decision-making processes. Nishimura et al. [7] compared audience impressions of an educational robot presentation with those of a computer animated agent presentation. Their results showed that the robot resulted in enhanced impressions on audiences. Thus, physical robots are expected to be useful as aids in many interactive fields including entertainment, education, security, rescue and elderly care. Furthermore, a high probability exists for robots to become successful social actors in mixed-reality environments.

Recently studies in the field of education have researched the application of technology to support and increase motivation in classrooms [12], [13], [14]. These studies have concluded that students who are motivated to learn are more likely to engage, persist, and expend effort in completing tasks than students who are unmotivated. Although learning is a complex process that cannot be understood by merely analyzing human responses to the attributes of technology, previous research showed that certain technologies can be used to enhance student motivation [12]. Therefore, educational robots can be considered a step in the evolution of educational technology, and numerous models have been successfully implemented in educational applications. Previous studies have revealed that educational robots can communicate effectively and enhance student enjoyment and engagement in classrooms [5], [8], [15], [16], [17].

The Japan Robotics Association, United Nations Economic Commission, and International Federation of Robotics have indicated that using personal robots for entertainment and educational purposes has recently experienced considerable growth, and they anticipated that this trend would continue over the next few years [18], [19]. Increasingly more studies have incorporated educational robots as tools for supporting educational activities, because they offer new benefits in educational environments [20]. Papert [21] showed that children can learn new skills by designing and

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assembling their own physical robots; moreover, robotics-related activities offer considerable potential for improving classroom instruction. Similarly, Cooper et al. [22] asserted that educational robots can capture the imagination of young learners, and their practical potential is high in numerous applications including enabling disabled students to interact with the environment. Kanda et al. [5] employed educational robots as social partners to interact with children. The robots encouraged students to improve their English ability while promoting their interest in English. Chang et al. [10] used an educational robot as an instructional tool to support language teachers at an elementary school. The teachers indicated that the robot created an interactive and engaging learning experience by attracting and maintaining the students' interest in instructional material and facilitating the development of problem-solving skills.

However, educational robots remain relatively undeveloped [1]. Empirical evidence supporting the importance of using robots in classroom environments is scant [19], [23]. Recently, Benitti [19] reviewed numerous studies that used educational robots to motivate students to learn. Benitti stated that research on this subject is typically descriptive, and the involved findings are based only on the reports of teachers who have achieved positive outcomes based on personal initiatives. In addition, further empirical evidence is required to confirm the effectiveness of educational robots. Thus, the potential for educational robots requires further research. Specifically related to elementary education, investigating the impact of educational robots on student motivation and learning outcomes is crucial.

Therefore, this study focused on the potential for using educational robot-based learning systems as instructional tools in classroom settings to enhance the learning performance and motivation of primary school students. This study proposes an educational robot-based learning system to provide instructional strategies by combining multimedia objects with an educational robot. The proposed system includes a simple editing tool that teachers can use to create instructional materials that incorporate external multimedia objects, to engage students in learning. In addition, teachers can program the robot to engage and motivate students to participate and learn. The proposed system can be programmed to generate a set of robotic behaviors to supplement audio or multimedia presentations, and further support teachers in creating a robotics-based learning environment.

This study conducted a trial evaluation to explore the impact of the proposed system at an elementary school in Taiwan. The participants comprised one homeroom teacher and 52 second-grade students from two classes. The homeroom teacher randomly assigned one class as the experimental group, and the other class was assigned as the control group. The evaluation results were obtained by collecting and analyzing data from various sources including pre-test, post-test evaluations and a questionnaire survey. First, this study evaluated the learning performance of students who were instructed using the proposed system and compared it with that of students who were taught using a PowerPoint-based learning system. The results showed that the students who were taught using the proposed system significantly outperformed those learning from the PowerPoint-based system. Second, the Instructional Materials Motivation Survey (IMMS) developed by Keller [24], [25], [26] was adapted to measure four motivational factors; attention, relevance, confidence, and satisfaction (ARCS). The ARCS model was originally developed as a descriptive model for diagnosing problems associated with learning motivation [27]. Several previous studies have validated and applied this model in research on applying computer technology as a motivational factor in learning [28], [29], [30]. Serio et al. [31] stated that each component of the ARCS model plays a critical role in motivating students throughout the learning process. Therefore, this study adopted the ARCS model to evaluate the motivation levels of primary school students who were instructed using the proposed educational robot-based learning system. The survey results showed that the students were highly motivated by the proposed system. Subsequently, a follow-up experimental study was proposed to assess the effectiveness of the proposed learning system in advancing classroom learning motivation in elementary education.

The remainder of this paper is organized as follows: Section 2 describes the system architecture of the proposed learning system, explains the design of extended markup language (XML)-based documents, and presents examples of instructional materials. Section 3 details the evaluation methods employed in this study, including an overview of the research setting and instructional materials. The experimental and qualitative survey results are presented in Section 4. In addition, the findings and experiments are discussed in Section 5. Finally, Section 6 offers concluding remarks.

2 The Educational Robot-Based Learning System

2.1 System Design and Architecture

Fig. 1 shows an overview of the system architecture of the proposed educational robot-based learning system. The system software environment includes an editing tool and material transformation server. Teachers can use the editing tool to author instructional content and to embed relevant multimedia objects into the lesson. The material transformation server receives the instructional content and controls devices that deliver the content in a hardware environment.

Relevant external devices, such as computer screens, loudspeakers and robotics kits, were placed in the hardware environment. The computer monitors were used to present images and text, and the loudspeaker was used for audio playback. The Robotis Bioloid Kit (ROBOTIS, Seoul, South Korea) [32] was adopted as a simple physical tutor to engage student attention. The customized platform consists of numerous components and small modular servomechanisms for users to construct various types of robot (e.g., hexapod or humanoid robots), as well as a ZIG2Serial component to interface the robot with a ZigBee communication module installed in a personal computer. In addition, the kit includes powerful graphical user interface (GUI)-based software tools such as the Motion Editor and Behavior Control Program, which can be used to generate and program the robot's motions and motion sequences. These software

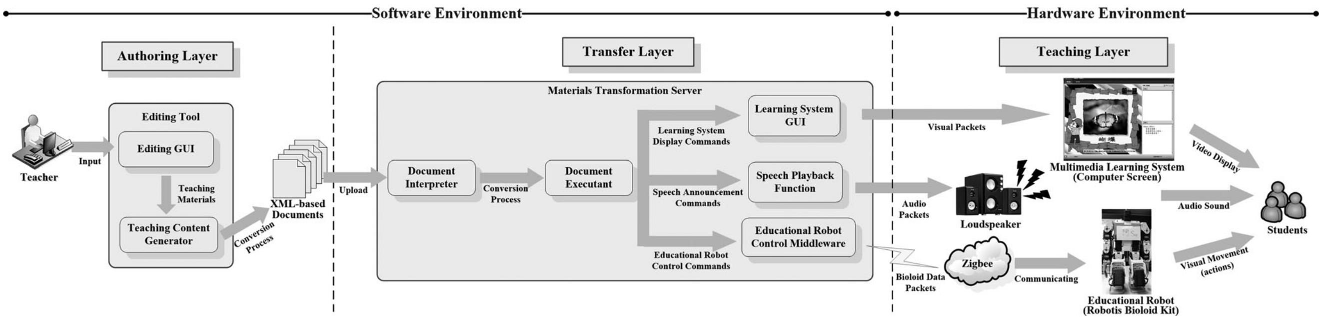


Fig. 1. The system architecture of the educational robot-based learning system.

tools can be employed to create novel motion sequences and to set multiple predefined actions for the robot to perform. The Bioloid Robot Kit has been considered the most cost-effective instructional tool for educational research [32].

Fig. 1 depicts how the various components interact and function in a three-layer environment (i.e., authoring, transfer, and teaching). The figure also illustrates the various work stages involved in the educational robot-based learning system. First, the authoring layer comprises an editing tool and XML-based documents. The editing tool employed in this study was developed using Java Platform Standard Edition 6 (Oracle, Redwoord Shores, CA, USA). This editing tool includes the following two modules: 1) an editing GUI, and 2) a teaching content generator. Teachers can use the editing GUI to select appropriate multimedia objects and corresponding behaviors for the robot to perform. Subsequently, the teaching content generator converts the teaching materials into XML-based documents. In other words, the editing tool is a simple user-friendly interface that teachers can use to create, delete, and modify XML-based documents intuitively. Teachers are not required to understand XML tags to create an XML-based document; thus, no programming knowledge is necessary in using the proposed system.

Second, the transfer layer encompasses a material transformation server that converts and executes the XML-based documents by invoking various modules to create engaging presentations. The material transformation server comprises the following five primary modules: 1) a document interpreter, 2) a document executant, 3) a learning system GUI, 4) a speech playback function, and 5) educational robot control middleware. When an XML-based document is uploaded to the server, the document interpreter converts it into various commands, such as learning system display, speech announcements, and educational robot control commands. These commands are received by the document executant, which consequently calls the learning system GUI, speech playback function, and educational robot control middleware. When the learning system GUI receives a display command, it generates a visual packet, which is a precursor for the multimedia learning system. Similarly, when the speech playback function receives an announcement command, it creates an audio packet containing a prompt to play an audio file. When the educational robot control middleware receives a control command, it translates it into Bioloid data packets that are implemented by the JavaComm application in conjunction with the ZigBee communication module in order to control the robot's movements.

Third, the teaching layer supports the integrated educational processes occurring between the physical devices and students. This layer entails employing three types of physical device (i.e., a computer screen, loudspeaker, and robot) that facilitate presenting the educational robot-based learning system. The multimedia learning system displays instructional content on the computer screen, plays audio files over the loudspeaker, and uses the robot as a teaching assistant to present the instructional content through various actions or physical movements.

2.2 Design of XML-Based Documents

This study adopted XML tag structures to describe and produce instructional content. XML documents feature high human-readability, and they are self-descriptive. In addition to promoting interoperability, XML documents are easy to maintain and extend [33], [34]. Essentially, this study designed numerous XML-based document tags to assemble prompts for the proposed educational robot-based learning system.

Table 1 shows the tag definitions for the XML-based documents used in this study. The seven primary tags used in the proposed learning system are <ID>, <Motion>, <Speech>, <Text>, <Delay>, <Reference>, and <Next>. The <ID> tag indicates a unique number (i.e., the key value) for identifying an XML-based document. The <Motion> tag indicates codes for specific actions that the educational robot performs. For example, the educational robot has several predefined actions such as "Wave," "Sad," "Greet," "Think," and "PointRight." Teachers without in-depth programming knowledge can easily specify the robot's actions by using the <Motion> tag. The <Speech> tag is used to identify the audio files used for the robot's

TABLE 1
The Tags of XML-Based Document

Tag Title	Tag Definition
ID	The number assigned to an XML-based document
Motion	Pre-defined actions of the educational robot
Speech	The educational robot's sound file (e.g. .wav or .mp3)
Text	The written text of the robot's sound content
Delay	A pause in the robot's action
Reference	External multimedia sources (e.g. PowerPoint slides)
Next	The subsequent XML-based document in the queue

The source code of XML-based document

```
<Document>
    <ID>sample001</ID>
    <Motion>PointRight</Motion>
    <Speech>tts_lookpoint.wav</Speech>
    <Text>Look at this place.</Text>
    <Delay>3</Delay>
    <Reference> butterfly_lifecycle.jpg </Reference>
    <Next>sample002</Next>
</Document>
```

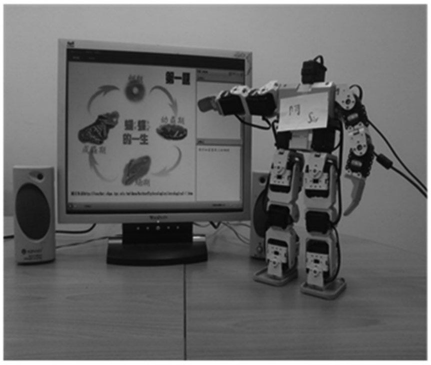


Fig. 2. An example of an XML-based document.

sound effects. Teachers must input the name of the source material (i.e., a WAV or MP3 audio file) and upload the corresponding files. The <Text> tag is used to define the text for showcasing the sound content of the robot. The <Delay> tag is used to insert a pause into the robot's action queue until an audio file has finished playing. In addition, external multimedia sources can be embedded using the <Reference> tag. In this study, the <Reference> tag was employed to incorporate relevant images. Finally, the <Next> tag identifies the subsequent XML-based document in a sequence.

Fig. 2 shows an example of the XML-based document format. The XML tags <Motion> and <Delay> direct the robot to perform the "PointRight" action and then pause for 3 s. The <Text> and <Reference> tags specify the multimedia objects for presenting the instructional content. The <Text> tag showcases the robot's sound content (i.e., "Look at this place."), and the <Reference> tag displays the image (i.e., "butterfly_lifecycle.jpg") on the computer monitor. Furthermore, the <Speech> tag specifies the audio file "tts_lookpoint.wav" as the robot's voice.

2.3 Implementing the Editing Tool and Instructional Materials

This study developed an editing tool to simplify the process of creating and authoring XML-based documents for teachers to supplement their curricula. The editing tool enables teachers to develop customized presentations by selecting actions for the robot and by embedding multimedia objects into the instructional materials. Moreover, teachers require no prior knowledge of XML tags to produce instructional materials. The editing tool can be used to directly author XML-based documents for creating multimedia-rich, interactive, and effective lessons for engaging students in the learning process.

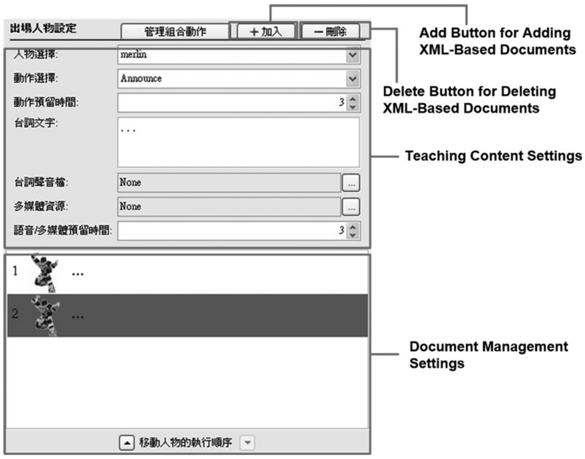


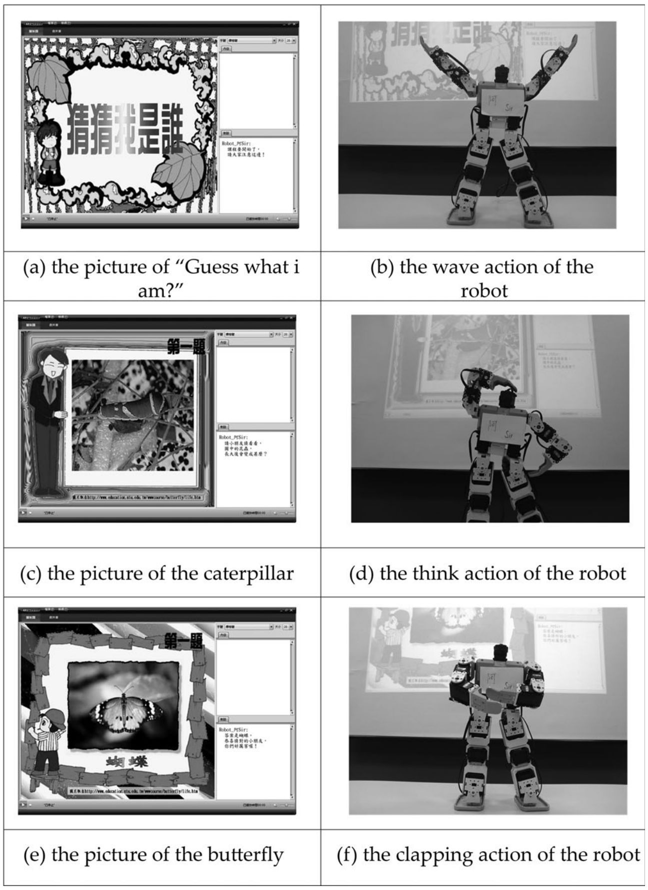
Fig. 3. The screenshot of the editing tool.

Fig. 3 shows the editing tool GUI. The two buttons located at the top right of the GUI ("Add" and "Delete") can be pressed to add or remove XML-based documents Teachers can add XML-based documents to deploy multimedia objects or configure the robot's motions through the GUI widgets located in the Teaching Content Settings panel, which enables teachers to convert instructional content into <Motion>, <Speech>, <Text>, <Delay>, and <Reference> tags. Subsequently, the sequence of XML-based documents is displayed in the Document Management Settings panel, which is used for viewing, editing, and rearranging the <Next> tags. In addition, through the Document Management Settings panel, teachers can select XML-based documents and modify their content. Finally, the editing tool combines all of the inputs to generate a new XML-based document. All of these operations can be performed easily by using a mouse and keyboard.

The instructional materials and teaching actions performed by the educational robot were generated using the proposed editing tool. Assume that at the beginning of a lesson, a teacher presents a slide displaying the text "Guess what I am?" (Fig. 4a), and then announces that a robot is going to introduce the topic of insects. Subsequently, the robot raises its arms above its head and waves both hands to encourage the students to pay attention (Fig. 4b). After the robot introduces an image of a caterpillar (Fig. 4c), the teacher asks the students what the caterpillar will eventually become. Subsequently, the teacher asks which one of them wants to tell the answer to the robot. The robot then raises its right arm and places its hand on its head to imitate a person thinking; this action is performed to cue the students to look at the monitor (Fig. 4d) to answer the question. When a student provides the correct answer, the teacher can show an image of a butterfly on the monitor (Fig. 4e), and the robot makes a sound of acclamation and performs a clapping motion to imitate a person expressing joy (Fig. 4f).

3 Evaluation Methods

To investigate the effectiveness of the proposed educational robot-based learning system and compare it with that of a PowerPoint-based learning system, this study conducted a series of controlled experiments at an elementary school in Taiwan. On completing the experiments, a pre-test, post-



(a) the picture of "Guess what i am?"
(b) the wave action of the robot
(c) the picture of the caterpillar
(d) the think action of the robot
(e) the picture of the butterfly
(f) the clapping action of the robot

Fig. 4. Examples of instructional materials with the robot's actions.

test, and questionnaire survey were conducted to evaluate educational robot-based learning system in promoting students' learning motivation. This study was conducted to achieve the following two research objectives:

1) Determine the effect on student's learning performance between using the educational robot-based and PowerPoint-based learning systems.
2) Identify which critical factors motivate students to learn by using the proposed educational robot-based learning system.

3.1 Participants

The participants comprised one homeroom teacher and 52 second-grade students from Shin-Guang Elementary School (Taichung City, Taiwan). The students' homeroom teacher was requested to supervise the experiment. The teacher had more than 12 years of teaching experience at the school, and exhibited high proficiency in designing PowerPoint-based presentations. The 52 second-grade students were from two classes. One class has 25 students and the other class has 27 students. Among the students, 27 of them were boys and 25 were girls. The mean age of the students was 8.7 years ($SD = 0.73$). One class ($N = 25$) was assigned to use the proposed learning system (the experimental group), whereas the other class ($N = 27$) was assigned to use the PowerPoint-based learning system (the control group).

Prior to the experiment, the homeroom teacher was instructed on how to use the proposed learning system. The experiment was conducted in conjunction with the homeroom teacher's regular class schedule. The educational robot was used as a tutor to aid the teacher in presenting the experimental teaching method in a classroom setting.

3.2 Instructional Materials

The lesson content presented in this experimental study was in accordance with the Science and Technology class curriculum. The instructional content was adapted from a fourth-grade textbook approved by the Ministry of Education, Taiwan. The learning goals of this course are outlined as follows: 1) to understand the growth environment and living conditions of six insects; 2) to understand the life cycle of six insects; and 3) to understand the relationship between plants and these six insects. Attending the lessons was anticipated to enhance the students' knowledge of the insect world.

For the experiment, a classroom was furnished with desks, chairs, and a ceiling-mounted screen for use with an overhead projector. For the PowerPoint-based learning system, audio instructions were played through loudspeakers, and PowerPoint slides were projected onto the screen in synchronization with the instructions. For the educational robot-based learning system, a robot was placed on a lectern at the front of the classroom to present the teaching actions clearly to the students. When appropriate, the robot performed gestures and pointed at the screen while the audio instructions were played over the loudspeakers. Additionally, to ensure that the instructional content was delivered without problems, the homeroom teacher was consulted to create the instructional material and plan the robot's behavior before conducting the experiment.

3.3 Procedure

Fig. 5 shows an overview of the experimental procedure employed in this study. At Stage 1, all students completed a 40-min pre-test, which was used to evaluate their prior knowledge on the experimental material. The pre-test had a maximum total score of 100. This study conducted the learning activities over a six-week period to avoid the novelty effect, in which user performance typically improves when new technologies are instituted, despite the improvement not reflecting actual advancement in learning or achievement [35]. Throughout this period, the novelty effect decreased as the students became more familiar with the two teaching systems.

At Stage 2, the students were allocated 40 min to complete specific in-class learning activities every week. The homeroom teacher introduced the metamorphosis of various insects to each group by using different formats. The interpersonal communication between the teacher and the students was observed in a classroom setting. In the experimental group, the educational robot was considered a teaching assistant that performed comical actions or played sound effects to further engage the students. For example, if the students were required to focus on the course content, the teacher would announce that the students should listen to the robot. Fig. 6a shows that when the teacher asked the students what the robot had said, the students stood up and listened carefully to the robot. When asking quiz questions

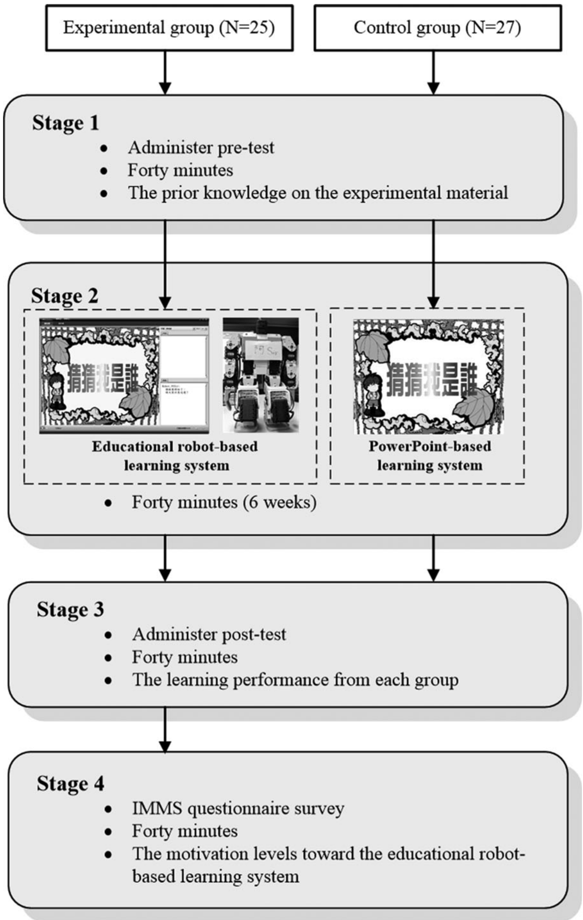
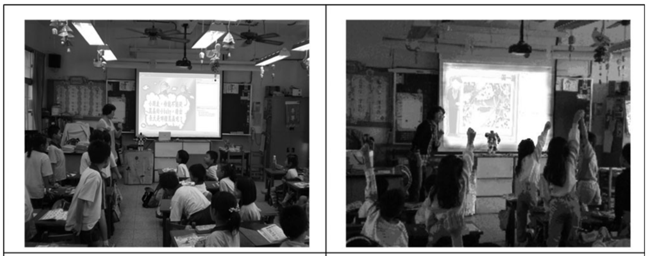


Fig. 5. The experimental procedure of students outlining the timeline and stages associated with the study.

on the course content, the teacher asked the students which one of them wanted to tell their answer to the robot. Fig. 6b shows the students enthusiastically raising their hands and providing their answers to the robot. For the control group, the teacher proceeded with delivering the instructional content by using traditional methods. All activities were guided by the teacher, and teaching materials such as PowerPoint presentations were used to deliver the content.

At Stage 3, after completing the learning activities, both student groups were required to complete a 40-min post-test during the final week of the study. All questions in the post-test were designed by the homeroom teacher. The post-test comprised 20 multiple-choice questions (4 points each) and four question-response problems (5 points each). The maximal score of the post-test was 100 points.

This study adapted the IMMS instrument to measure the degree of the students' motivation to learn by using the proposed educational robot-based learning system. The IMMS was designed to assess learner motivation, and each question is related to one of the four factors in the ARCS model [24], [25], [26]. The first factor, attention, emphasizes that a lesson must gain and sustain a learner's curiosity, arousal, and interest. The second factor, relevance, is related to how well a connection is formed between the instructional content and the learning needs and goals of the students. The third factor, confidence, is related to how successfully a student accomplishes specific learning objectives. The final factor, satisfaction, is related to the student's positive feelings



(a) students focus on the robot. (b) students answer to the robot.

Fig. 6. The teacher and the robot teaching collaboratively.

toward the learning experience. Previous studies have employed the IMMS as both a qualitative and quantitative evaluation technique for measuring findings [36], [37], [38].

This study adapted the IMMS questionnaire to evaluate the motivation of primary school students toward the proposed educational robot-based learning system. The terminology used in the survey questions was modified to suit the context of this study. The IMMS originally comprised 36 questions that are measured using a five-point Likert-scale, on which the items are ranked from 1 (*strongly disagree*) to 5 (*strongly agree*). Two questions were removed to ensure the students' comprehension.

At Stage 4, after the students in the experimental group completed the posttest, they were allocated 40 min to complete the aforementioned questionnaire survey. The students in the experimental group were required to complete the questionnaire; thus, the response rate was 100 percent. Z scores were calculated to detect any outliers, and the results ($z = \pm 3.0$) indicated that no survey response should be eliminated.

After the experimental procedure was complete, an interview was conducted to evaluate the homeroom teacher's professional and personal assessment of the proposed educational robot-based learning system.

4 Evaluation Results

The experimental results show that the proposed educational robot-based learning system exerted a considerable impact on the students' learning performance. Furthermore, the questionnaire survey results indicate several potential benefits of using educational robots.

4.1 Research Objective 1

Determine the effect on student's learning performance between using the educational robot-based and PowerPoint-based learning systems;

Table 2 shows the mean and standard deviations of the test scores of both student groups. The independent samples t-test was employed to analyze the difference between pre-test and post-test scores. In addition, this study used Cohen's d to calculate the strength of the relationship between the two groups based on the standardized difference between the two means. Cohen's d explains the effect size, and d values of 0.2, 0.5, and 0.8 correspond to small, medium, and large effect sizes, respectively [39]. All statistical analyses were performed with an alpha value of 0.05.

Table 2 lists the mean pre-test grades of the experimental ($M = 74.36$) and control ($M = 75.26$) groups. The t-test

TABLE 2
Descriptive Statistics for Pre/Post-Test Scores between Two Groups

System	Pre-test		Post-test	
	Mean	SD	Mean	SD
Experimental group (N = 25)	74.36	13.219	90.84	10.609
Control group (N = 27)	75.26	11.336	79.78	17.656
t-test	0.213		0.001*	

$^{*}\ p < 0.05$.

results show that the difference between the pre-test scores of the two groups is non-significant ($t = -0.264$, $p > .05$), indicating that the two groups possessed a comparable degree of knowledge on the content of the experimental material. The table also shows the post-test scores of both groups. The t-test results show that the test performance of the experimental group improved significantly ($t = 2.493$, $p < .05$). In addition, the post-test results show that the experimental group ($M = 90.84$, $SD = 10.609$) outperformed the control group ($M = 79.78$, $SD = 17.656$). The Cohen's d result (0.759) indicates that the effect size was medium-to-large.

The results of this study show that the mean post-test grades were higher than the pretest grades from both groups. However, the experimental group scored higher than the control group did, demonstrating a significant change in learning performance. This may be attributed to the educational robot-based learning system facilitating students' learning motivation and encouraging them to pay more attention in the classroom. In summary, the mean grades of the experimental group were higher than those of the control group, indicating that the proposed educational robot-based learning system effectively improved the students' learning performance.

4.2 Research Objective 2

Identify which critical factors motivate students to learn by using the proposed educational robot-based learning system.

Cronbach's alpha was calculated to confirm the reliability of the adapted IMMS questionnaire based on the experimental group survey data. The reliability of the original IMMS is 0.85, indicating that the instrument is highly reliable for assessing student motivation. Moreover, the modified IMMS questionnaire used in this study comprised 34 questions whose responses were measured on a scale ranging from 1 to 5; thus, the total possible score ranged from 34 to 170. The total score of the IMMS survey data exhibited a mean of 149.2, with scores ranging from 115 to 170. This result indicates that most students were motivated by the proposed educational robot-based learning system.

Table 3 shows the descriptive statistics of the four factors of the ARCS model. The satisfaction factor yielded the highest mean score ($M = 4.81$), indicating that the students were satisfied when using the proposed educational robot-based learning system to learn new content. The table also shows that the other factors yielded high mean scores, with mean values of 4.59, 4.69, and 4.55 for the attention, relevance, and confidence factors, respectively. These results indicate that the proposed system effectively gained the students' attention. The customized lesson plan and learning activities were in close alignment with the students' learning objectives. Overall, most of the students felt more confident in learning the Science and Technology course content. The high mean scores of all four factors indicate that the students were highly motivated when interacting with the proposed educational robot-based learning system.

TABLE 3
Descriptive Statistics of the Four Factors

Factor	Mean	SD
Attention	4.59	0.59
Relevance	4.69	0.52
Confidence	4.55	0.64
Satisfaction	4.81	0.41

Table 4 lists the 12 questions used for measuring the attention factor of the ARCS model. The mean scores are higher than 4.0 for all 12 questions, eight of which yielded mean scores higher than 4.5. These results indicate strong agreement among most of the students regarding the effectiveness of using the proposed educational robot-based learning system for maintaining attention while learning in the Science and Technology course. In particular, Question 15 yielded the highest mean score ($M = 4.84$), providing direct evidence that the educational robot helped the students to remain focused on the instructional materials. In addition, more than 96 percent of the students specifically reported that the proposed educational robot-based learning system helped in maintaining attention. Collectively, these results show that most of the students were attentive when the educational robot was used as a tutor during the instructional activities. Several previous studies have shown that educational robots can make learning environments more entertaining [5], [6]. The presentations of the educational robot are attention-grabbing and can help students to focus on the learning tasks. More than 97 percent of the students disagreed with the statement that the presentations made by the educational robot were unappealing in a classroom setting.

Table 5 shows the mean scores and standard deviations of the seven questions employed in this study for measuring the relevance factor of the ARCS model. All seven questions yielded mean scores higher than 4.0, six of which exceed 4.6. These results indicate that the design of the learning content and activities was crucial and relevant to the students' need to learn the course content. Questions 22 and 25 yielded the highest mean scores ($M = 4.88$ for both), indicating that more than 97 percent of the students were in agreement that the educational robot-based learning system was a crucial factor of how they perceived the presented information. Moreover, more than 92 percent of the students reported that the content of the proposed learning system was relevant to their learning objectives. Finally, more than 96 percent of the students agreed that the involved learning activities were useful to them when the educational robot was used.

Table 6 shows the mean scores and standard deviations of the nine questions that this study used to measure the confidence factor of the ARCS model. Overall, the confidence factor

TABLE 4
Mean Scores and Standard Deviations of the Attention Factor

No.	Question	Mean	SD
2	The educational robot is attention-grabbing.	4.08	0.57
3	The educational robot helped to hold my attention.	4.32	0.69
11	The educational robot makes the lesson so abstract that it was hard to pay attention to the lesson. (Reverse)	4.72	0.46
12	The presentation of the educational robot looks boring and unappealing. (Reverse)	4.80	0.50
15	The variety of the educational robot's presentations helped to keep my attention on the instructional material.	4.84	0.37
17	The educational robot in the learning activity presented information that stimulated my curiosity.	4.48	0.77
19	The repetitive actions of the educational robot in the learning activity caused me to get bored. (Reverse)	4.48	0.82
21	Interesting instructional materials presented in the educational robot-based learning system caught my attention.	4.60	0.58
23	I learned some things from the educational robot-based learning system that were surprising or unexpected.	4.56	0.65
27	The way the multimedia objects are arranged in the educational robot-based learning system helped to keep my attention.	4.76	0.52
28	The presentation of the educational robot-based learning system was boring. (Reverse)	4.76	0.52
29	The presentation of the educational robot-based learning system was irritating. (Reverse)	4.80	0.63

yielded a mean score higher than 4.0, indicating that the students were confident in using the educational robot-based learning system to learn the instructional material. Question 18 yielded the highest mean score ($M = 4.88$), indicating that most of the students disagreed strongly with the statement that the instructional material was difficult to associate with the educational robot's actions. Additionally, more than 84 percent of the students reported that they felt confident about improving their score or passing a test after learning course content through the proposed learning system. More than 96 percent of the students were in agreement that the organization of the content presented by the proposed system enhanced their confidence in learning the instructional material. According to previous studies, educational robots can act as social partners or peer tutors, thereby exerting a positive effect on the learning experience of students [5], [6]. Similarly, the results of this study confirm that integrating educational robots and multimedia objects can make students more interested in course content and increase their confidence.

Table 7 shows the mean scores and standard deviations of the six questions employed in this study to measure the satisfaction factor of the ARCS model. Overall, the satisfaction factor yielded a mean score exceeding 4.7. Individually, two of these questions yielded mean scores higher than 4.9. The scores obtained for Question 34 yielded the highest mean score ($M = 4.96$), indicating that the students were satisfied with learning the Science and Technology course through the educational robot-based learning system. Moreover, more than 96 percent of the students reported that the proposed educational robot-based learning system assisted them in completing the course exercises, and it elicited a sense of accomplishment. The scores for Question 26 also yielded a mean score exceeding 4.9, indicating that the students had positive feelings when the educational robot provided feedback or encouragement. Finally, more than 96 percent of the students reported that they felt positive and successful when learning the instructional content, and their learning was aided by the presence of the educational robot.

5 Discussion

This study employed the proposed educational robot-based learning system as an instructional tool for motivating and engaging students in learning relevant course content in a

TABLE 5
Mean Scores and Standard Deviations of the Relevance Factor

No.	Question	Mean	SD
6	It is clear to me how the content presented by the educational robot-based learning system is related to my previous knowledge on the topic.	4.72	0.54
9	There was information that demonstrated how the educational robot-based learning system could be important to some people.	4.64	0.49
10	Completing this course successfully after using the educational robot-based learning system was important to me.	4.32	0.80
16	The content presented by the educational robot-based learning system was relevant to my interests.	4.64	0.70
22	The content presented by the educational robot-based learning system conveys the impression that the instructional content was worth learning.	4.88	0.33
25	This learning activity was not relevant to my needs because I already knew most of the information presented. (Reverse)	4.88	0.33
31	This learning activity will be useful to me for future applications.	4.76	0.44

TABLE 6
Mean Scores and Standard Deviations of the Confidence Factor

No.	Question	Mean	SD
1	When I first saw the educational robot-based learning system, I had the impression that this course would be easy for me.	4.36	0.75
3	The instructional materials and learning activity was more difficult to understand than I would have liked it to be. (Reverse)	4.12	0.83
4	After learning with the educational robot-based learning system, I felt confident that I had effectively learning the content of this course.	4.44	0.71
5	The educational robot-based learning system presented so much additional information that it was hard to remember the important points from the instructional materials. (Reverse)	4.60	0.58
13	As I learned the information from the educational robot-based learning system, I was confident that I could remember the content.	4.80	0.50
18	It was difficult to understand the instructional materials in association with the educational robot's actions. (Reverse)	4.88	0.33
24	After learning with the educational robot-based learning system for a while, I was confident that I would be able to pass a test on the course materials.	4.36	0.76
32	I could not really understand the instructional material that was presented by the educational robot-based learning system in this course. (Reverse)	4.64	0.76
33	The good organization of the content presented by the educational root-based learning system gave me confidence that I would learn the instructional material.	4.76	0.52

classroom setting. The results were obtained by collecting and analyzing data from various sources, including pre-test and post-test evaluations, as well as a questionnaire survey. The following sections discuss several problems investigated by this study.

5.1 Effect on Student Learning Performance between Two Learning Systems

The pre-test and post-test results indicate the students' learning performance when using the PowerPoint-based learning system alone or in combination with the proposed educational robot-based learning system. The results of this study show that the proposed learning system significantly improved the students' learning performance based on the four factors of the ARCS model. The possible reasons for this finding are explained as follows:

1) The educational robot is equipped with a tangible user interface and physical characteristics that attract the attention and interest of students. The attention factor was evident in the students' interest toward the learning activities. The qualitative survey results indicate that the educational robot affected the students' motivation to learn, and it ensured that the students were attentive. This may motivate students to immerse themselves in various learning activities. Xie et al. [40] asserted that when people interact with tangible objects, they naturally become more engaged with the objects than they would by simply watching a video. Furthermore, Chang et al. [10] claimed that educational robots may encourage students to focus more on their work in the classroom. Benitti [19] stated that educational robots could potentially engage young people with a wide range of interests. Most of the students who were surveyed in this study reported a positive attitude toward interacting with the educational robot, and showed considerable interest in the robot's behaviors. Therefore, the educational robot may have encouraged the students to focus on their learning activities.
2) The educational robot guided the students to help them comprehend their learning objectives through various gestures and behaviors. The relevance factor of the ARCS model explains how effectively a system meets the learning needs and goals of students. The qualitative survey results show that the students considered the learning content presented by the educational robot-based learning system to be crucial and relevant to their learning interests. The students who were surveyed at the end of the study reported that the course content that was delivered using the proposed learning system was worth knowing and learning. However, because the instructional materials were similar for both systems, this study must assume

TABLE 7
Mean Scores and Standard Deviations of the Satisfaction Factor

No.	Question	Mean	SD
5	Completing the exercises in the lessons gave me a satisfying feeling of accomplishment.	4.72	0.54
14	I enjoyed the educational robot-based learning system so much that I would like to continue to learn in this manner.	4.76	0.44
20	I really enjoyed studying with the educational robot-based learning system.	4.72	0.57
26	The feedback or encouragement of the educational robot used in this course helped me feel rewarded for my efforts.	4.92	0.28
30	It felt good to successfully learn with the educational robot-based learning system.	4.76	0.44
34	It was a pleasure to learn from such a well-designed learning activity.	4.96	0.20

that neither the course content nor typical multimedia objects exerted a strong impact on the students' perceptions. Li et al. [6] asserted that robots could assume the role of teaching assistants to direct students to focus on the crucial concepts in their course materials. You et al. [41] employed an educational robot to motivate students to learn English, reporting that the students concentrated diligently while listening to the robot and observing its actions and movements. Therefore, this study asserts that educational robots can support students by connecting instructional content with their own learning needs, and further affect student performance.

3) The educational robot encouraged the students to complete their learning tasks. The confidence factor of the ARCS model measures the students' sense of control and expectancy of success. The qualitative survey results show that the students felt confident about what they learned through the proposed educational robot-based learning system. In this study, two systems were deployed using identical instructional materials and content (i.e., image presentations and text). Thus, the instructional content did not affect the students' performance markedly. Shinozawa et al. [11] used a virtual character and a robot to compare human decision-making processes in mixed-reality learning environments. The realistic robot was strongly associated with high ratios of successful task completion. In this study, most of the students were confident about passing the posttest after learning from the proposed educational robot-based learning system. Therefore, the proposed educational system may have encouraged students to improve their performance considerably for the follow-up tests.
4) The educational robot leaves a favorable impression on students. The satisfaction factor of the ARCS model can measure the positive feelings students have toward their learning experience. The qualitative survey results show that the students felt positive and were motivated to engage in the learning activities when they received encouragement from the educational robot. Nishimura et al. [7] asserted that physical robots are effective tools for presenting multimodal content, because robots can perform exaggerated actions that animate presentations. That study compared users' impressions of a physical robot's presentation with a virtual character's presentation. The physical robot was evaluated more favorably, because the robot was considered more charming, and it made a favorable impression. Chang et al. [1] asserted that realistic robots make people feel more comfortable and are more likeable overall [1]. Therefore, this study argues that educational robots can effectively enhance student motivation to learn and improve overall learning performance.

5.2 Critical Factors Motivating Students to Learn with the Educational Robot-Based Learning System

The results of this study indicate that integrating the proposed educational robot-based learning system into the students' current learning environments motivated them to learn. Based on the mean scores of each ARCS model factor, satisfaction was rated the highest ($M = 4.81$) among the four factors. The results show that the students were satisfied when the proposed educational robot-based learning system was used to support their learning activities. The satisfaction factor, which was defined as the fulfillment of a need or want (Questions 5, 30, and 34), yielded mean scores of more than 4.7, indicating that a considerably high level of satisfaction was achieved using the proposed system. Regarding the evaluation of enjoyment, the results of this study indicate that the students enjoyed working with the educational robot, as indicated by the mean scores of Questions 14 ($M = 4.76$) and 20 ($M = 4.72$). Additionally, the overall mean score of the relevance factor ($M = 4.69$) was rated second among the four factors. The mean scores of four of the seven questions measuring relevance exceeded 4.7, implying that the students were pleased to fulfill an academic requirement in alignment with their expectations.

Overall, the attention and confidence factors of the ARCS model yielded mean scores of 4.59 and 4.55, respectively. Moreover, 7 of the 12 questions used to measure the attention factor yielded a mean score exceeding 4.6, indicating that the proposed educational robot-based learning system can assist teachers in gaining and holding the attention of students in classroom environments. In addition, the confidence factor, which is related to the students' feelings of personal control and expectancy of success, can influence their learning efforts. Five of the nine questions for measuring the confidence factor yielded mean scores exceeding 4.6. In general, the students who participated in this study were confident that they could comprehend the instructional materials and learning activities.

5.3 Classroom Observations on Using the Educational Robot-Based Learning System

During the learning activities, the students in the experimental group exhibited high levels of interest when interacting with the educational robot. Regarding robot usage, the students were highly satisfied and enthusiastically engaged in their learning activities when receiving encouragement from the robot. For example, after the robot introduced itself, the teacher asked the students whether they liked the robot. All of the students in the experimental group said "yes" immediately without further prompting. Additionally, when the teacher asked the students to raise their hand to answer the robot, the extroverted students responded quickly and answered the questions. This study found that the introverted students willingly participated in the learning activities when promoted by the teacher, and they offered answers to receive encouragement from the robot. Furthermore, the introverted students responded more frequently when asked a question in the presence of the robot.

Several students in the experimental group achieved high levels of concentration while engaging in the learning activities; they were enthusiastic to understand what the robot could do in the classroom. Furthermore, when the robot presented teaching actions, the students were silent and attentive. On completing the learning activities, the students immediately formed discussion groups to discuss the robot's characteristics including its voice, actions, and age. The behavior exhibited by the students indicates that the educational robot encouraged them to concentrate more, and they were more immersed in the learning activities.

However, during Week 5 of this study, the experimental group was less attentive to the educational robot. According to Kanda et al. [5], children quickly become highly motivated when a robot is present in the classroom. However, that study indicated that this type of stimulation is seldom maintained. The current study hypothesizes that the robot's influence on the students' interest depends on the robot's ability to integrate instructional activities that are appropriate for the students. Thus, it is difficult to create effective content for educational robots to interact with students, and to provide additional support in various collaborative learning activities for enhancing classroom orchestration [42], [43].

5.4 Interview with the Homeroom Teacher

On completing the experiment, the homeroom teacher was interviewed and requested to provide feedback on the proposed educational robot-based learning system. The teacher stated: "The result was great. All of the students hope to see the robot dance or clap for them, so they are willing to enthusiastically raise their hands to answer questions. The robot is a very good tool that supports my teaching and it engages the students." Regarding the execution of the experimental study, the homeroom teacher also provided the researchers with some suggestions: "Generally, each instructional unit was edited for 30-40 min. I created multimedia objects by using other software applications, such as Paint and Audio Recorder Platinum, which were not integrated into the proposed system, and thus I needed to spend extra time learning how to operate these external applications, which was inconvenient for me. Therefore, I recommend that the editing tool should feature an image editor and audio recorder. I would like to use the editing tool to create and edit images and record sounds directly." In summary, the teacher responded positively to using the proposed educational robot-based learning system in the classroom, and expressed interest in participating in follow-up research.

At the beginning of the experiment, the homeroom teacher expressed doubts about the practical value of the educational robot. Furthermore, the teacher possessed no knowledge about how to operate the robot. Therefore, this study consulted with an operations assistant to program the educational robot-based learning system and oversee the research. When necessary, the operations assistant provided guidance for the teacher on how to operate the proposed learning system. When the educational robot malfunctioned, the operations assistant immediately repaired and reinitiated the robot. Prior to commencing this study, it was crucial to instruct the teacher on how to use the educational robot-based learning system, and to allow time for the teacher to become familiar with the operation, configuration, and limitations of the proposed system.

6 Conclusion

This study describes an educational robot-based learning system that can provide elementary school teachers with a tool to enhance the learning performance of students. Teachers with or without relevant technical expertise can easily program the proposed learning system and integrate robotic behaviors into accompanying multimedia objects and presentations. Furthermore, the proposed system can provide additional support for teachers in creating a robotics-based learning environment. With an appropriate level of technological support, teachers can easily incorporate multimedia objects and educational robots into their teaching regime, with demonstrable benefits for students.

The statistical results obtained in this study provide a suitable basis for analyzing the educational benefits of this research:

1) The quantitative results of this study show that using the proposed educational robot-based learning system in a classroom environment exerted a positive effect on the learning performance of the students, implying that the proposed system can assist in enhancing students' learning efficiency.
2) The qualitative results show that the students were motivated to use the proposed educational robot-based learning system, thus indicating the potential benefits of integrating educational robots into instructional and learning activities. Thus, educational robots can be used to motivate students to learn more, and they can be used to attract interest to improve learning efficiency further.

Some limitations were encountered while conducting this empirical study. First, the Robotis Bioloid Kit was adapted into the educational robot used in this study. However, the robot was too small for class with more than 20 students. The robot was too small to meet the visual needs of the students. For example, when the students seated at the rear of classroom did not stand, they were unable to see the robot clearly. With advancements in robotics, inexpensive robots could be developed to be more suitable for classroom settings. Second, this study needs to consider the issue of classroom orchestration and come up with a method to appropriately integrate computer-supported technologies in the classroom [42], [43]. Without integrating appropriate instructional content and activities, the proposed learning system offers few advantages in supporting teaching practices. Hence, future studies should consider designing a simple human-robot interface for teachers to manipulate and control educational robots. Such an interface would allow teachers to structure, plan, and implement their lessons more effectively, thereby empowering them beyond the training process provided by the researchers. Third, the experiment was conducted at only one elementary school in Taiwan; thus, the evaluation results can explain only the teaching efficacy of the proposed learning system in Taiwanese elementary education environments. Future studies on educational robot-based learning systems can be extended into various educational systems such as high school or colleges. Finally, this preliminary study was conducted as a trial evaluation to examine the educational potential of applying robotics in elementary schools. Future studies should considering using stricter statistical analysis methods to structure the experimental results and link the findings with theoretical studies.

In summary, this study indicates that the proposed educational robot-based learning system can create a learning experience that interests and engages students. Compared with other instructional tools, the proposed system is advantageous because it enhances student motivation. With the presence of the proposed educational robot-based learning system as an instructional tool, teachers may have additional time for students experiencing difficulty in learning the lesson content, while maintaining the learning experience of other students. Consequently, increasingly more educators could easily incorporate educational robot-based learning systems into their instructional activities in the future.

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