Designing and Evaluating an Attention-Engagement-Error-Reflection (AEER) Approach to Enhance Primary School Students Artificial Intelligence Literacy and Learning-to-Learn Skills: A Pilot Study

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Abstract: This paper reports on a mixed-method pilot study that designed and evaluated an Attention-Engagement-Error-Reflection (AEER) approach to enhance primary school students' artificial intelligence (AI) literacy and learning-to-learn skills. A total of 35 Grade six primary school students in Hong Kong were involved. Both quantitative and qualitative data were collected and analyzed. Data collection included (1) pre-, post-, and delayed post-AI concepts tests, (2) pre- and post-questionnaires on learning-to-learn skills, and (3) six focus group interviews. The results demonstrated the positive impact of the proposed AEER approach on students' AI conceptual understanding and learning-to-learn skills. Students' motivation in the learning process was analyzed. Finally, limitations and future directions were discussed.
Keywords: Innovative pedagogical design, artificial intelligence literacy, learning-to-learn skills, motivation

1. Introduction

With the rapid advancement of technology, the importance of artificial intelligence (AI) literary education has emerged as a global topic (Dwivedi et al., 2021). The goal of AI literacy education is to equip individuals with the fundamental AI concepts, empower students to participate effectively in a digital society, raise awareness of the ethical use of AI, and enable them to collaborate with AI systems in their daily lives (Kong et al., 2023; Su et al, 2023). However, the potential of AI literacy education to foster learning-to-learn skills in K-12 educational contexts remains largely unexplored (Azevedo & Wiedbusch, 2023).

To address this gap, the present pilot study was designed to develop and evaluate an innovative pedagogical approach - the Attention-Engagement-Error-Reflection (AEER) approach, implemented using the AlphAI learning robots. This approach aimed to enhance primary students' AI literacy and learning-to-learn skills. Additionally, the study explored students' motivation during the learning process. The following three questions were addressed:

(1) What is the impact of an AEER approach on students' AI conceptual understanding?
(2) What is the impact of the AEER approach on students' learning-to-learn skills?
(3) How does the AEER approach support learners' motivation?

2. Literature Review

2.1 Using Robots for Developing Artificial Intelligence Literacy

Educational robotics applications are increasingly being utilized to enhance students' learning experiences and stimulate their interests in the areas of STEM (science, technology, engineering, and mathematics and AI (Su et al.,2023). Despite the great potential of robots in engaging learners (Zhong & Xia, 2020), most of these applications require an understanding of algorithms and programming skills, posing an accessibility challenge for beginners, particularly in primary education contexts (Noh & Lee, 2020). Empirical research has suggested that the use of educational robotics applications could positively influence academic performance (Al Hakim et al., 2022). Despite the growing interest in AI literacy education, rare studies have been explored in the literature regarding the effective integration of learning robots through innovative pedagogical design.

2.2 Using Robots for Developing Learning-to-Learn Skills

Learning-to-learn skills refer to individuals' ability to monitor, regulate and control their own learning activities (Cornford, 2002) to learn effectively in various contexts. The learning-to-learn skills are not only vital for academic success but also facilitate students to become lifelong learners, helping students become more adaptable and resilient in the face of new challenges and changing learning settings (Thrun & Pratt, 2012).

In this pilot study, learning-to-learn skills were adapted from Flavell's (1979) and Schraw and Moshman's (1995) model of metacognition, including metacognitive knowledge (i.e., individual's views as a learner and beliefs about their ability to learn) and metacognitive regulation (i.e., setting goals, monitoring, and reflecting). Despite the need for nurturing learning-to-learn skills in primary education (e.g., Vainikainen et al., 2015), few studies have explored using robots in AI literacy education to engage young students in an interactive way.

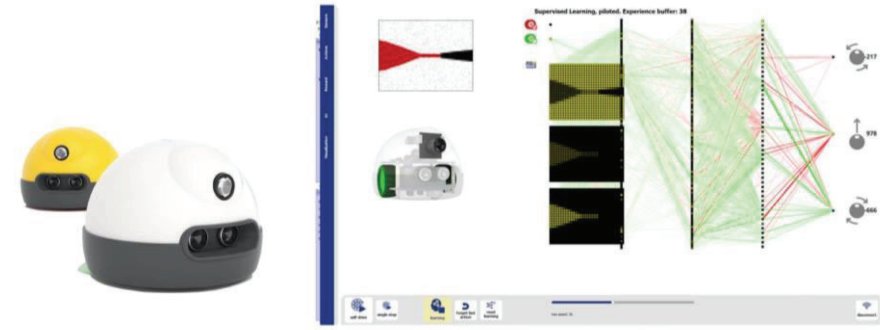
2.3 Understanding Students' Motivation in AI Literacy Education

A number of studies have showed the vital role of motivation in AI literacy education (e.g., Kong et al., 2021). One commonly used motivational design model is the attention, relevance, confidence, and satisfaction (ARCS) model proposed by Keller (1987). Attention focuses on capturing students' curiosity. Relevance involves relating learning to students' goals and interests. Confidence aims to build students' self-efficacy of competence. Satisfaction enables students to apply their new learned knowledge. The ARCS model provides useful guidance for understanding and enhancing student motivation. However, few studies have examined primary school students' motivation using the ARCS model in the context of AI literacy education.

3. Research Design

3.1 The AlphAI Learning Robots

The AlphAI learning robots (https://learningrobots.ai/?lang=en) used in this study aimed to provide learners with hands-on experience and graphical interfaces to visualize AI algorithms in machine learning and deep learning (Martin et. al., 2023). Each robot, as shown in Figure 1(a), was connected to the AlphAI software, illustrated in Figure 1(b). The AlphAI software helps visualize the workings of neural networks and how machines learn and allow students to take control of the robots by using the arrows on the computer keyboard.



(a). The AlphAI learning robots

(b). Visualisations of algorithm in the form of an artificial neural network on screen (i.e. supervised learning)

Figure 1. The AlphAI Learning Robots.

3.2 Participants

In this pilot study, a convenience sampling approach was adopted (Etikan et al., 2016) due to the close communication of researchers and the teachers from the selected schools. Thirty-five Grade six primary school students (22 boys and 13 girls) with average age of 11.54 in Hong Kong were involved. Regarding the research ethics associated with data collection from the participants, written informed consent was obtained from both the students and their parents prior to commencement of the study.

3.3 Pedagogical Design: Attention-Engagement-Error-Reflection (AEER) Approach

Figure 2 shows the proposed pedagogical design. The AEER approach was adapted from Dahaene’s four pillars of learning (2020), including attention, active engagement, error feedback, and consolidation. To be specific, the first component in the AEER approach is to harness learners’ attention. This was achieved via the use of the AlphAI learning robots. The use of the AlphAI learning robots in an educational setting could spark curiosity and interest among students, thereby effectively focusing their attention on the learning task.

The next step was to promote active engagement through collaborative learning. In this study, learners were organised into small teams, each consisting of 3-4 students, to facilitate collaborative learning. A “play-learn-play” strategy, emphasising ‘learning by doing’, was implemented. The learning journey commenced with students interacting with the AlphAI learning robots. This was followed by the delivery of conceptual knowledge, seamlessly integrated with hands-on activities, enabling students to apply the theoretical constructs practically and instantaneously. The culmination of this learning experience was a robot racing competition, providing an opportunity to manifest their newly acquired knowledge and skills in a competitive yet enjoyable setting. This cyclical process of play, learn, and play again aimed to help students remain actively engaged, thereby enhancing their motivation, understanding and retention of the AI concepts, and learning to learn from robots.

The third component in AAER approach is error, encouraging students to learn from their trial-and-error experiences with the AlphAI learning robots. In each robot racing competition, the robots would find themselves in situations not encountered during the initial training (for example, getting stuck on an edge of the arena, or on another robot). If the robot could not move, students were encouraged to observe the mistakes made by the robots and took control of the robot with the on-screen arrows or the keyboard under the guidance of a tutor in each group. This process aimed to foster a growth mindset in students, as they began to perceive errors as learning opportunities rather than failures.

The fourth component is reflection. By reflecting on students’ learning process, they can gain a deeper understanding of strengths and weaknesses, identify their learning strategies, and develop plans for improvement.

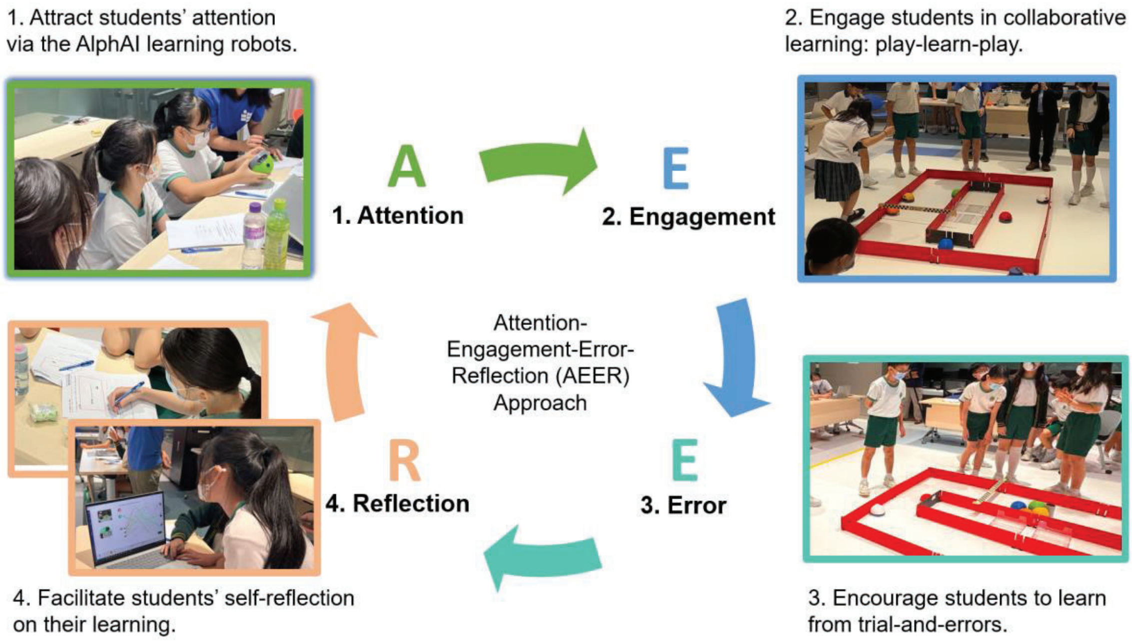


Figure 2. The Proposed AEER Approach.

3.4 Research Procedure

The pilot study lasted for two weeks, including a two 3-hour workshops. The concepts of machine learning, deep learning, supervised learning, and reinforcement learning were covered. In the first workshop, students were introduced to basic concepts of AI, supervised learning and reinforcement learning by training the robots. In the second workshop, students applied the knowledge learned in the first workshop and reflected on their learning to train the robots to avoid obstacles in a new environment.

Before the first workshop, the students completed a pre-test of AI concepts and a pre-survey on learning-to-learn. After the second workshop, the students completed a post-test of AI concepts and a post-survey. A total of 29 students were invited to participate in the interviews on a voluntary basis. After one week, participants were invited to complete the delayed post-tests to measure the retention of AI concepts.

3.5 Data Collection and Analysis

In this study, data sources included (1) pre-, post-, and delayed post-AI concepts tests, (2) pre- and post-questionnaires on learning-to-learn, and (3) six focus group interviews, involving a total of 29 students. The instruments used in this study were jointly developed and validated through the collaborative efforts of two experts in AI literacy and two researchers specializing in metacognition. The AI concept test was used to assess students' AI conceptual understanding in machine learning and deep learning. The test was developed by the research team, including seven items. The questionnaire on learning-to-learn skills included four dimensions of goal setting, monitoring, reflection, and growth mindset with 11 items. The questions of focus group interviews were guided by ARCS motivation model to obtain more in-depth and comprehensive views regarding using AEER approach with the AlphAI learning robots for AI literacy education and learning-to-learn.

Quantitative data analysis was used to address the two research questions. For the first research question, a one-way repeated measures ANOVA was conducted. For the second research question, paired sample-t-tests were used. For the third research question, content analysis was used to analyze focus group interviews to understand primary students' learning motivation in using AlphAI learning robots via AEER approach.

4. Results

4.1 AI Conceptual Understanding

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in the scores of conceptual understating of AI in pre-tests, post-tests, and delayed post-tests. The scores of AI tests were statistically significantly different at the different time points, $F(2, 68) = 43.23$, $p < .001$, partial $\eta^2 = .56$.
Post hoc analysis with a Bonferroni adjustment revealed that the scores were statistically significantly increased from pre-tests to post-tests ($M_{diff} = 2.34$, 95% CI [1.66, 3.03], $p < .001$), and from pre-tests to delayed post-tests after one week ($M_{diff} = 2.11$, 95% CI [1.37, 2.86], $p < .001$). Although there was a slight decrease from delayed post-tests to post-tests ($M_{diff} = -.23$, 95% CI 1.65, 3.03], $p > .05$), no significant difference was observed.

4.2 Leaning-to-Learn Skills

Paired sample-t-tests were conducted to determine whether there were statistically significant differences in the scores in the pre-and post-surveys. The results showed that students learning-to-learn skills improved in terms of four dimensions: goal setting, monitoring, reflection, and growth mindset. Overall, there was a statistically significant increase in students' learning-to-learn skills from the pre-survey to the post-survey ($M_{diff} = 0.11$, 95% CI [0.03,0.04], $p < .05$).

4.3 Interview Results

Beyond the significant improvement in the test and survey, the focus group interviews indicated that using the AlphAI learning robots via the AEER approach improved students' learning motivation. The focus group interviews showed that the majority of interviewees agreed that the AlphAI learning robots made AI learning interesting and engaging, thereby enhancing their learning motivation.

Regarding "attention", all of the students felt that the AlphAI learning robots aroused their attention. The interactive nature of the robots, which could be controlled through keyboard inputs and provided visual feedback, sparked students' curiosity. Some interviewees (pseudonyms were used) further explained:

- *"Controlling the robots was like a game, and I was also learning at the same time."* (Charles)
- *"Using the robots to learn AI was novel. I have never experienced it before."* (Cindy)

In terms of "relevance", the interviews indicated that controlling robots was relevant to their learning. For example, one student said, "I feel that supervised learning is similar to us being supervised by teachers or parents. They accompany us as we study. On the other hand, reinforcement learning requires time to learn. That is, if we rush to finish learning something and then cram for tests, we will not be able to achieve good results because we are not yet familiar with the materials".

Regarding "confidence", the majority of students stated that the learning led to increased confidence in their ability to learn and understand AI. Claire shared, "At first, AI seemed daunting, but after using the robot and reflecting on what I learned, I feel more confident. I believe I can master AI on one day."

Finally, in relation to "satisfaction", the overall positive feedback suggest that students found the AEER approach and the use of the AlphAI learning robots satisfying. All of the students reported they would like to join the workshop to learn AI if given opportunity. A number of students said they were motived to learn more about AI after attending the study.

5. Conclusion

The pilot study demonstrated promising results regarding the impact of the AEER approach on enhancing primary school students' AI conceptual understanding, learning-to-learn skills, and motivation. The findings of the study show that students' overall learning outcomes and learning-to-learn skills increased significantly. The findings suggest that the AEER approach holds considerable potential for the future of education, providing a model for how we can equip students with the knowledge and skills they need to prepare for an AI-infused future.

A number of avenues for future research are suggested. First, the sample size of this pilot study was small. Thus, it would be beneficial to replicate the study with a larger and more diverse sample in order to generalize the findings. Second, the intervention duration of this study was short. Therefore, longitudinal studies will be conducted to examine the long-term effects of the AEER approach on students' AI literacy and learning-to-learn skills. Lastly, research could explore the integration of the AEER approach across various age groups (i.e., secondary school students, university students), and how the approach can be tailored to meet the specific needs of different learners.

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