Using the Robot-Assisted Attention-Engagement-Error-Feedback-Reflection (AEER) Pedagogical Design to Develop Machine Learning Concepts and Facilitate Reflection on Learning-to-Learn Skills: Evaluation of an Empirical Study in Hong Kong Primary Schools

Siu-Cheung Kong[1,2][a] and Yin Yang[2][b]

[1]*Artificial Intelligence and Digital Competency Education Centre, The Education University of Hong Kong, HKSAR, China*

[2]*Department of Mathematics and Information Technology, The Education University of Hong Kong, HKSAR, China*

Keywords: Learning-to-Learn, Machine Learning, Neuroscience-Informed Pedagogical Framework, Primary Schools, Robots.

Abstract: This paper presents the results of an empirical study that aimed to evaluate the effectiveness of using robots to teach machine learning concepts to primary school students and consolidate their reflection on learning-to-learn skills. The pedagogical design of this study was based on the neuroscience-informed Attention-Engagement-Error-feedback-Reflection (AEER) framework. The study involved 87 Grade 5 students from Hong Kong. Data collection included pre- and post-tests on machine learning concepts, as well as pre- and post-questionnaires on learning-to-learn skills based on the AEER framework. The findings suggest that the use of purposely designed robots for understanding machine learning significantly enhanced primary school students' understanding of machine learning concepts. Further, it can facilitate students' reflection on their learning-to-learn skills, which have been nurtured over their years of study period, thereby effectively preparing them for the transition to secondary school education. The paper concludes with a discussion of the findings and provides potential directions for future research.

1 INTRODUCTION

Artificial intelligence (AI), and in particular machine learning, is transforming the global world. The promotion of AI literacy to all young learners in their schooling can empower them to have an identification as part of the future AI society. In this context, the experiences from teaching machines to learn using supervised learning and/or reinforcement learning offer young learners' unique opportunities to reflect on their own learning skills.

AI education is pivotal in nurturing students into educated citizens equipped to thrive in an AI-prevalent future (Kong et al., 2022; Kong et al., 2023). Learning-to-learn skills, regarded as the capacity of individuals to self-regulate, monitor, and control their learning activities (Cornford, 2002), are of crucial importance in the contemporary AI-driven society.

Despite the need for consolidating learning-to-learn skills in education (e.g. Vainikainen et al., 2015), very few studies have explored using robots in machine learning to engage young students and connecting machine learning to facilitate reflection on learning-to-learn (Martin et al., 2023; Kong & Yang, 2023). This study aimed to conduct an empirical study on the application of robots, which are purposely designed for uncovering the black box of machine learning, to develop Hong Kong senior primary students' machine learning concepts and to facilitate the consolidation of learning-to-learn skills, based on their past years of study period in schools. The following research questions were addressed in this study: Research question 1: To what extent do primary students enhance their understanding of machine learning concepts through the pedagogical activities? Research question 2: To what extent do primary students enhance the consolidation of learning-to-learn skills?

[a] https://orcid.org/0000-0002-8691-3016
[b] https://orcid.org/0000-0002-9966-248X

Kong, S. and Yang, Y.
Using the Robot-Assisted Attention-Engagement-Error-Feedback- Reflection (AEER) Pedagogical Design to Develop Machine Learning Concepts and Facilitate Reflection on Learning-to-Learn Skills: Evaluation of an Empirical Study in Hong Kong Primary Schools.
DOI: 10.5220/0012505700003693

In *Proceedings of the 16th International Conference on Computer Supported Education (CSEDU 2024) - Volume 2*, pages 155-162
ISBN: 978-989-758-697-2; ISSN: 2184-5026

2 LITERATURE REVIEW

2.1 Using Robots to Support Primary Students' Machine Learning

Machine learning is a subfield of AI, which has complex and abstract concepts that can be hard for young students like primary school students to understand (Zimmerman, 2018). Despite the inherent difficulty of teaching these concepts to young learners like primary school students, there is a growing interest in integrating machine learning education into K-12 educational settings, aiming to prepare young learners for an AI-infused future (Lin et al., 2020).

One of the frequent challenges for educators introducing machine learning-related content is the complexity of technical terms and the need to present these terms in a manner that engages students and sustains their interest (Kong & Yang, 2023). In response, several user-friendly platforms such as Teachable Machine and Dancing with AI have been adopted to engage beginners who are interested in machine learning. However, these platforms often fall short of explaining the algorithms that drive the machines (Voulgari et al., 2021).

Given that the integration of machine learning in K-12 education is a relatively new area of research focus, there is a need for empirical studies that employ innovative approaches to enrich this developing domain (Sanusi et al., 2023). One promising approach is to help students understand machine learning concepts using robots. Various studies have used robots to elucidate AI and machine learning concepts to students (Al Hakim et al; 2022; Olari et al., 2021; Williams et al., 2019). For instance, the Preschool-Oriented Programming (PopBots) Platform, which includes a social robot toolkit comprising a smartphone, LEGO blocks, motors, and sensors, was used to help preschool students know machine learning (Williams et al., 2019). This platform allowed the kindergarten students to talk to the robots and use a block-based interface to code. Similar studies have also been explored the use of coding to create applications with simulated robots (e.g. Olari et al., 2021). Although the block-based approach is child-friendly, it does not necessarily facilitate children's understanding of the underlying algorithms of machine learning (Jatzlau et al., 2019).

In our present study, we utilised AlphAI robots (https://learningrobots.ai/?lang=en) to help non-programming senior primary school students in Hong Kong to understand machine learning concepts. This platform is designed purposely to uncover the black box of machine learning. The system presents graphical visualisations to assist students in understanding the underlying algorithms, such as K-nearest neighbours, supervised learning using deep learning approach, and reinforcement learning.

2.2 Facilitating Learning-to-Learn Skills in Machine Learning

Learning-to-learn skills, also known as metacognitive skills, are crucial for fostering students' independence and enhancing problem-solving and critical thinking abilities (Cornford, 2002). When students are in their early stages of education, they already possess these fundamental learning-to-learn abilities (McCombs, 1991). Students are encouraged to maintain concentration on learning, engage in practical activities, actively conduct hands-on activities, engage in peer discussions, correct errors, and reflect on their learning experiences through K-12 education settings (Jocz et al., 2014).

Although it is common for primary school students to participate in activities that promote the development of these skills, there is a lack of instructional methods that specifically target active reflection on the significance of learning-to-learn skills (Ashford & DeRue, 2012).

Existing research on the use of robots in machine learning education primarily focused on students' perception of machine learning, their motivation, and engagement (Burgsteiner et al., 2016; Kammer et al., 2011; Olari et al., 2021; Williams et al., 2019). However, the extent to which the teaching of machine learning concepts using purposely designed robots can facilitate the reflection and consolidation on learning-to-learn skills of young students is still unknown.

Using robots in machine learning education offers a unique opportunity to senior primary school students to reflect on learning-to-learn skills. Moreover, learning machine learning with robots also involves iterative learning, where students can progressively improve the robot's performance, learn from their mistakes, evaluate their strategies after receiving or observing feedback, and apply different approaches (Voulgari et al., 2021). This process can assist students in understanding the importance of persistence, repetitive/deliberate practice, and reflection in learning.

2.3 Neuroscience-Informed Pedagogical Framework in Primary AI Education

In the existing literature, most pedagogical frameworks for AI education in primary schools tend to employ game-based or project-based learning approaches (Voulgari et al., 2021; Lee et al., 2021). However, cognitive scientists argue for the creation of a novel pedagogical framework that fosters deep, authentic, and collaborative learning, drawing upon insights from neuroscience (Hardiman, 2012). The field of neuroscience has provided significant contributions in understanding the process of human learning (Immordino - Yang et al., 2007). These contributions can be effectively utilised to enhance the educational practises of AI. According to Jamaludin et al. (2019), neuroscience-informed pedagogical framework can facilitate the alignment of teaching tactics and approaches with the inherent learning processes of the brain. By employing such an approach, educators can effectively enhance students' comprehension of AI and machine learning, sustain their engagement in the learning process, and foster the acquisition of crucial skills that are essential for future endeavours. However, neuroscience-informed pedagogical frameworks can rarely be found in primary AI education.

Against this backdrop, Kong and Yang (2023) proposed the Attention-Engagement-Error-Feedback-Reflection (AEER) pedagogical design, which is informed by the four fundamental principles of learning delineated by Dehaene (2020), a prominent cognitive neuroscientist from France. The robot-assisted AEER pedagogical design aligns with findings from the learning sciences and emphasises the importance of fostering a deeper understanding of machine learning concepts and seeks to emphasise and reinforce learning-to-learn skills. While game and project-based learning can be effective for initial engagement and exposure to AI concepts, they may fall short in facilitating the deeper cognitive processes that AEER targets. For instance, games may capture attention and engagement, they may not always provide the specific, targeted feedback necessary for students to recognize and understand their errors, nor the scaffolding to guide reflection on why an error occurred.

3 THE ROBOTS USED IN THIS STUDY

In this study, the AlphAI robots were used to teach primary students' machine learning in a concrete and precise manner, effectively "opening the black box of AI" (Learning Robots, n.d.). Each robot is connected to the AlphAI software (refer to Figure 1). The robot is packed with sensors (e.g. wide-angle camera, ultrasound, infrared line tracking sensors), so it can recognise via an inbuilt camera. The AlphAI software provides a graphical representation of AI algorithms, such as K-nearest neighbours (KNN), artificial neural network (ANN), and reinforcement learning. Moreover, it allows students to directly control the robot using arrows on the keyboard or clicking the arrows on the screen. As the quality of robot training is also influenced by the robot's environment, the playing arena was set to facilitate robot movement. Figure 2 depicts the specific arena of training robots.

Figure 1: The AlphAI robot and software.

Figure 2: The arena for training AlphAI robots.

4 CURRICULUM DESIGN

4.1 The Attention-Engagement-Error-Feedback-Reflection (AEER) Pedagogical Framework

The AEER pedagogical framework (Kong & Yang, 2023) was implemented in this study. To be specific, in "Attention", students were directed to identify important and relevant information, highlight important and relevant concepts in the worksheets, and understand the importance of maintaining and refocusing attention after taking a short break throughout the learning process.

In "Engagement", the course stimulated active engagement by kindling students' curiosity in training robots to learn machine learning. The course promoted peer discussions, provided hands-on activities, and offered real-time feedback. Students were invited to observe the robots' performance and recorded their observations in the worksheets.

In "Error-feedback", students were taught to formulate hypotheses, test them, and make corrections based on the feedback received. For instance, they are encouraged to hypothesise whether larger K values (K can set from 1 to 100) would yield improved results when using KNN algorithm and test their hypotheses in training sessions.

In "Reflection", students were invited to review their goals or sub-goals, share their reflections with others, revise plans to improve their training, and compare machine learning with human learning.

4.2 Machine Learning and Learning-to- Learn Course Design

The course design covered (1) introduction to AI, (2) exploration of three concepts of machine learning: K-nearest neighbours (KNN), artificial neural network (ANN), and reinforcement learning, and (3) integration learning-to-learn skills into learning activities based on the robot-assisted AEER pedagogical framework.

4.2.1 Introduction to AI

The course provided a foundational understanding of AI, discussing its definition and exploring different types of machine learning such as unsupervised learning, supervised learning, and reinforcement learning. It also introduced the four main steps involved in machine learning: defining the problem, collecting and cleaning data, training the model, evaluating the model, and making inferential conclusions.

4.2.2 Exploration of Three Concepts of Machine Learning

Students learnt three concepts via training AlphAI robots. (1) K-nearest neighbours (KNN). The AlphAI software provides an interactive interface that allows students to delve into the workings of the K-Nearest Neighbours (KNN) algorithm. As part of the learning experience, students can observe how robots make decisions by considering the proximity of their nearest neighbours. (2) Artificial neural network (ANN). The structure of an ANN (e.g., input, hidden, output layers) is visualised in the AlphAI software. In ANN, nodes are called neurons. The strength of connections between neurons is represented by lines in the AlphAI software. (3) Reinforcement learning. It is a type of machine learning where an agent (in this case, AlphAI learning robots) learns to make decisions by performing actions and receiving feedback from its environment. Every time the robot moves, it can receive rewards, the value of *Level* is determined by the average rewards obtained per minute. The robot starts with no knowledge of its environment and begins to take random actions, learning from the consequences of these actions. The robot receives a reward when it successfully moves; whereas it receives a penalty when it gets stuck. The robot improves its performances via utilising these rewards and penalties.

4.2.3 Integration Learning-to-Learn Skills into Learning Activities Based on the AEER Pedagogical Framework

The following section explains how the AlphAI robots were incorporated into the learning activities, with specific focus to each area of the AEER framework. Regarding "Attention", the AlphAI robots are utilized to introduce students to core principles of supervised learning (KNN, ANN) and reinforcement learning. These robots use attention mechanisms, such as image capturing and recognition to "learn" how to move. To parallel this, learning activities are crafted to enhance students' attention. Worksheets with text hints, images, and illustrations are utilized to guide students in concentrating on the task at hand, such as through exercises like naming the robot or using thought bubbles. In developing learning-to-learn skills, students are instructed on setting clear goals and subgoals for their robot training sessions. They learn to identify vital information and underscore key machine learning concepts. In addition, an emphasis is also placed on the need for relaxation and refocusing.

Regarding "Engagement", in the concept of supervised learning, students directly interact with the learning process through hands-on activities. When the robots encounter obstacles on the track in KNN and ANN activities, students are encouraged to supervise the robots to observe and then moves again. Students need to explore the effect of adjusting the value of K in KNN activities. In reinforcement learning, the robots adapt their actions based on rewards and penalties. Students need to observe how the robots learn. In developing learning-to-learn skills, The teacher(s) enhance students' engagement by sparking students' curiosity to explore new knowledge, facilitating peer discussions, guiding hands-on activities, observing, and recording. Students are encouraged to engage in deliberation until they understand the reasons of success and sources of obstacles when they supervise the robots to learn, and these activities serve as foods for thoughts in reflecting how students learn with open-minded observation and engagement in their daily learning.

Regarding "Error-feedback", robots encounter obstacles in moving forward such as hitting a wall and getting stuck in a corner. Students need to supervise the robots to act appropriately by providing opportunities to encounter obstacles and find ways to overcome. Students need to spend quite a substantial period in supervising the robots to overcome the obstacles and these provide opportunities for students to reflect. In parallel, these activities are designed to help students reflect on their own learning. Students observe errors made by robots during training, such as hitting walls and getting stuck, and adjust their strategies accordingly. Rather than viewing errors as failures, they are guided to consider these as learning opportunities. The teacher guides students in understanding and rectifying errors made by the robots and helping them understand the importance of seeking for feedback. Students are encouraged to engage in repetitive practices until the obstacles are resolved in supervising the robots to learn and these activities serve as foods for thoughts in reflecting how students learn with perseverance to overcome learning barriers in daily learning.

The "Reflection" stage is where students synthesize learning activities and evaluate their cumulative learning experiences. In the case of robot training, students can apply different algorithms such as KNN, ANN, and reinforcement learning, each with its unique advantages and limitations, to train their robots for a racing challenge. Through this process, students came to understand that qualitative data plays a pivotal role in the robot's performance. When faced with obstacles, such data can assist the robot in performing well in "self-driving". In developing learning-to-learn skills, students are guided to consider various strategies to enhance their understanding and to seek out new methods for overcoming conceptual challenges. This reflective practice is vital for developing a growth mindset. Students are not merely passive recipients of knowledge but are actively engaged in figuring out how to learn and apply new concepts.

5 METHODOLOGY

5.1 Participants

The convenience sampling approach was adopted (Etikan et al., 2016). The teacher from the selected school had previously worked closely with the researchers on other research projects.

A number of 87 Grade 5 students (girls = 43.7%, boys = 56.3%) from five classes aged between 9 and 10 participated in a two-day workshop. In compliance with ethical considerations involving participant data, signed consent forms were obtained from the students and their parents before initiating the study.

During the workshop, the students were divided into twelve groups. The grouping was based on voluntary principles, allowing students to select their own group members (Rienties et al., 2014). Each group was provided with an AlphAI robot and a computer. A teaching tutor from the research team was assigned to assist two groups.

5.2 Research Procedure

The study included two 2-hour workshops. In the first workshop, students were introduced to basic concepts of AI and machine learning (e.g. unsupervised learning, supervised learning, and reinforcement learning) through hands-on robot training. The second workshop let students apply and reflect on the knowledge gained in the first, training robots to navigate a new environment while avoiding obstacles.

Before the first workshop, the students completed a pre-test of machine learning concepts and a pre-survey on learning-to-learn skills. The AEER pedagogical design was employed to deepen the students' understanding of supervised learning (KNN, ANN) and reinforcement learning. The task involved guiding a robot to move in a clockwise direction along the track after training (refer to Figure 2). After the second workshop, students completed a post-test on machine learning concepts, along with a post-survey.

5.3 Data Collection and Analysis

In this study, the data sources included (1) pre- and post-tests on machine learning concepts, and (2) pre- and post-surveys on learning-to-learn using a five-Likert scale (ranging from strongly disagree 1 to strongly agree 5).

The instruments used in this study were developed and validated through the collaborative efforts of three experts in AI education and two researchers specialising in metacognition.

The machine learning concept test was designed to assess students' conceptual understanding in machine learning and deep learning (refer to Appendix I). The test was designed based on Bloom's taxonomy and comprised eight items, with a Cronbach's alpha of 0.60. To be specific, two items assessed students' ability to recognise and recall the facts related to machine learning procedures. One item tested students' comprehension of the machine learning process. One item evaluated the students' problem-solving abilities using their understanding of KNN. Two items accessed students' evaluative skills by choosing the right statements about AI and reinforcement learning. One item focused on analysis, where students were asked to compare the differences between supervised and unsupervised learning. The final item required students to design a plan using the knowledge they acquired during the workshops.

The questionnaire on learning-to-learn skills included four dimensions of attention, engagement, error-feedback, and reflections with 15 items (refer to Appendix II). The Cronbach' alpha was above 0.80.

For the data analysis, to address RQ1, paired samples t-tests were used to compare the pre-and post-tests. To address RQ2, regarding the students' learning-to-learn skills in the context of AI education, the paired samples t-test was used.

6 RESULTS

6.1 Understanding Machine Learning Concepts

A paired samples t-test was conducted to determine whether there were statistically significant differences in the scores of conceptual understating of machine learning in pre- and post-tests. Table 1 shows the descriptive data of eight items of the test. A significant difference was observed between pre-, and post-test, $M_{diff} = 0.98$, 95% CI [0.52, 1.44], $p < 0.001$).

Table 1: Descriptive data and paired samples t-test of machine learning concepts.

Dimensions	Pre		Post		Paired samples t-test
	M	SD	M	SD	*t*
Item1	0.33	0.47	0.60	0.49	4.01***
Item2	0.17	0.38	0.45	0.50	4.40***
Item3	0.67	0.47	0.70	0.46	0.75
Item4	0.51	0.50	0.64	0.48	1.98*
Item5	0.25	0.44	0.39	0.49	2.25*
Item6	0.34	0.48	0.54	0.50	2.56**
Item7	0.31	0.47	0.63	0.49	5.32***
Item8	0.16	0.37	0.44	0.50	4.26***
Total Grade	2.75	1.51	3.72	1.81	4.22***

Note: M = mean, SD = standardised deviation
** p < 0.05, ** p < 0.01, *** p < 0.001*

6.2 Facilitating Reflection on Leaning-to-Learn Skills

Paired samples t-tests were conducted to determine whether there were statistically significant differences in the pre-and post-surveys. Table 2 shows the descriptive data that students learning-to-learn skills improved in terms of four dimensions: attention (M_{diff}= 0.43, 95% CI [0.25, 0.60], $p < .001$), engagement (M_{diff} = 0.31, 95% CI [0.14, 0.47], $p < .001$), error-feedback (M_{diff} = 0.23, 95% CI [0.04, 0.42], $p < 0.05$), and reflection (M_{diff} = 0.28, 95% CI [0.11, 0.44], $p < 0.001$) (refer to Figure 3). 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], $p < 0.05$).

Table 2: Descriptive data and paired samples t-test of Leaning-to-learn survey.

Dimensions	Pre		Post		Paired samples t-test
	M	SD	M	SD	*t*
Attention	3.59	0.78	4.02	0.68	4.86***
Engagement	3.71	0.69	4.01	0.73	3.74***
Error-feedback	3.72	0.74	3.95	0.73	2.45*
Reflection	3.64	0.74	3.92	0.66	3.38***
Average	3.67	0.60	3.97	0.62	4.56***

Note: M = mean, SD = standardised deviation
** p < 0.05, ** p < 0.01, *** p < 0.001*

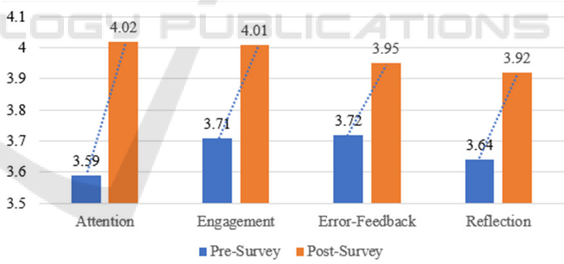

Figure 3: Students' perceptions of attention, engagement, error-feedback and reflection between pre- and post-survey.

7 DISCUSSION AND FUTURE WORK

This study aimed to address the current research gaps by focusing on adopting the neuroscience-informed AEER pedagogical design to enhance primary students' machine learning and facilitate students to actively reflect on their learning-to-learn skills. The results of this study showed the positive effectiveness of using robots underpinned by the AEER pedagogical design in enhancing primary students understanding of machine learning concepts and facilitating learning-to-learn skills gained from pervious studying periods. The findings are in line with prior research, where children showed interest in investigating why the robot failed to learn efficiently (Lin et al., 2020; Olari et al., 2021). Through observing and reflecting on the performance of robots, students can learn machine learning in a fun way. In addition, training robots to reflect on learning-to-learn deepen senior primary students' metacognitive skills. Thereby there is a potential to effectively preparing primary students for the transition to secondary school education, which needs more metacognitive skills. Although this empirical study is promising in integrating machine learning and learning-to-learn skills into primary education, further exploration is needed.

The study has contributed to both teaching and research. First, this study provides a novel pedagogical design that can help teachers make their instruction more effective and engaging in machine learning using robots. Furthermore, the study highlights the potential of the AEER as a guide for teaching strategies, especially in promoting learning-to-learn skills in machine learning. By integrating this model into teaching, educators may be able to foster a deeper understanding of the subject matter and enhance students' metacognitive skills. Second, this study provides a foundation for further research in developing primary students' machine learning concepts and facilitating learning-to-learn skills through the robot-assisted AEER. This research fills an existing gap in the literature and enriches the practices of using robots to teach machine learning at the primary school level. Furthermore, the positive results from the AEER model implementation indicate its potential for refinement across other subjects.

The study acknowledges three primary limitations. First, the curriculum design has incorporated machine learning with learning-to-learn into primary education via two 2-hour workshops. While this approach was novel, it may pose challenges for primary-aged children due to the length and difficulty. Even though we used comics and other visual aids to engage students in our worksheet designs, which were based on the characteristics of young learners, future curriculum designers should consider a variety of tactics to maintain students' attention and involvement during each two-hour workshop.

Second, the relatively low Cronbach's alpha of 0.60 in machine learning concept tests suggests the need for improving its reliability. Future studies will consider refining the test items or increase the number of items to improve its internal consistency.

Third, the AEER pedagogical design still needs further iterative refinement. By analysing the robots' performance and training robots, students were able to identify the differences and similarities between machine learning and human learning, while how to further help senior primary students reflect on learning-to-learn, especially for receiving feedback to overcome the obstacles in their learning need to be further discussed. Future research could include longitudinal research to investigate the long-term impacts of the pedagogical design on students' understanding of machine learning concepts and development of learning-to-learn skills.

ACKNOWLEDGEMENTS

The authors would like to acknowledge this artificial intelligence literacy project with the funding support from the Li Ka Shing Foundation and the Research Grants Council, University Grants Committee of the Hong Kong Special Administrative Region, China (Project No. EdUHK CB357).

REFERENCES

Al Hakim, V. G., Yang, S.-H., Liyanawatta, M., Wang, J.-H., & Chen, G.-D. (2022). Robots in situated learning classrooms with immediate feedback mechanisms to improve students' learning performance. *Computers and Education*, *182*, 104483–. https://doi.org/10.1016/j.compedu.2022.104483

Ashford, S. J., & DeRue, D. S. (2012). Developing as a leader: The power of mindful engagement. *Organizational Dynamics*, *41*(2), 146–154.

Burgsteiner, H., Kandlhofer, M., & Steinbauer, G. (2016). IRobot: teaching the basics of Artificial Intelligence in high schools. In *Proceedings of the Thirtieth AAAI Conference on Artificial Intelligence* (pp. 4126–4127). AAAI Press. USA.

Cornford, I. R. (2002). Learning-to-learn strategies as a basis for effective lifelong learning. *International Journal of Lifelong Education*, *21*(4), 357-368. International Publishing. https://doi.org/10.1007/978-3-31994640-5_13.

Dehaene, S. (2020). *How we learn: The new science of education and the brain*. Penguin UK.

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*, *5*(1), 1–4.

Hardiman, M. M. (2012). *The brain-targeted teaching model for 21st-century schools.* Corwin Press.

Immordino‐Yang, M. H., & Damasio, A. (2007). We feel, therefore we learn: The relevance of affective and social neuroscience to education. *Mind, Brain, and Education*, *1*(1), 3–10.

Jamaludin, A., Henik, A., & Hale, J. B. (2019). Educational neuroscience: Bridging theory and practice. *Learning: Research and Practice*, *5*(2), 93–98.

Jatzlau, S., Michaeli, T., Seegerer, S., & Romeike, R. (2019). It's not magic after all–machine learning in snap! using reinforcement learning. *In 2019 IEEE Blocks and Beyond Workshop (B&B)* (pp. 37–41). IEEE. https://doi.org/10.1109/BB48857.2019.8941208

Jocz, J. A., Zhai, J., & Tan, A. L. (2014). Inquiry learning in the Singaporean context: Factors affecting student interest in school science. *International Journal of Science Education*, *36*(15), 2596–2618.

Lee, S., Mott, B., Ottenbreit-Leftwich, A., Scribner, A., Taylor, S., Park, K., ... & Lester, J. (2021, May). AI-infused collaborative inquiry in upper elementary school: A game-based learning approach. *In Proceedings of the AAAI Conference on Artificial Intelligence*, *35*(17), 15591–15599.

Lin, P., Van Brummelen, J., Lukin, G., Williams, R., & Breazeal, C. (2020). Zhorai: Designing a conversational agent for children to explore machine learning concepts. *In Proceedings of the AAAI Conference on Artificial Intelligence*, *34*(09), 13381–13388.

Martin, M., Chevalier, M., Burton, S., Bonvin, G., Besançon, M., & Deneux, T. (2023). Effects of introducing a learning robot on the metacognitive knowledge of students aged 8-11, *Proceedings Robotics in Education*, Cyprus. https://doi.org/10.1007/978-3-031-38454-7_15

McCombs, B. L. (1991). Motivation and lifelong learning. *Educational Psychologist*, *26*(2), 117–127.

Kammer, T., Brauner, P., Leonhardt, T., & Schroeder, U. (2011). Simulating LEGO mindstorms robots to facilitate teaching computer programming to school students. In *Proceedings of the 6th European conference on Technology enhanced learning: towards ubiquitous learning* (pp. 196–209). Springer-Verlag.

Kong, S.-C., Cheung, W. M.-Y., & Tsang, O. (2023). Evaluating an artificial intelligence literacy programme for empowering and developing concepts, literacy and ethical awareness in senior secondary students. *Education and Information Technologies*, *28*(4), 4703-4724. https://doi.org/10.1007/s10639-022-11408-7

Kong, S.-C., Cheung, W. M.-Y., & Zhang, G. (2022). Evaluating artificial intelligence literacy courses for fostering conceptual learning, literacy and empowerment in university students: Refocusing to conceptual building. *Computers in Human Behavior Reports*, 7, 100223.

Kong, S.-C., & Yang, Y. (2023). 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. *In Proceedings of the 31st International Conference on Computers in Education Volume II* (pp.394-399), Shimane, Japan.

Olari, V., Cvejoski, K., & Eide, Ø. (2021, May). Introduction to machine learning with robots and playful learning. *In Proceedings of the AAAI Conference on Artificial Intelligence*, *35*(17), 15630–15639.

Rienties, B., Alcott, P., & Jindal-Snape, D. (2014). To let students self-select or not: That is the question for teachers of culturally diverse groups. *Journal of Studies in International Education*, *18*(1), 64–83.

Sanusi, I. T., Oyelere, S. S., Vartiainen, H., Suhonen, J., & Tukiainen, M. (2023). A systematic review of teaching and learning machine learning in K-12 education. *Education and Information Technologies*, *28*(5), 5967–5997. https://doi.org/10.1007/s10639-022-11416-7

Learning Robots. (n.d.). *The concept AlphAI, the robot made by Learning Robots. Discover AI.* Retrieved November 23, 2023, from https://learningrobots.ai/the-concept/?lang=en

Vainikainen, M. P., Wüstenberg, S., Kupiainen, S., Hotulainen, R., & Hautamäki, J. (2015). Development of learning to learn skills in primary school. *International Journal of Lifelong Education*, *34*(4), 376–392.

Voulgari, I., Zammit, M., Stouraitis, E., Liapis, A., & Yannakakis, G. (2021). Learn to machine learn: Designing a game-based approach for teaching machine learning to primary and secondary education students. *Proceedings of the 20th Annual ACM Interaction Design and Children Conference*, 593–598. https://doi.org/10.1145/3459990.3465176

Williams, R., Park, H. W., & Breazeal, C. (2019). A is for artificial intelligence the impact of artificial intelligence activities on young children's perceptions of robots. *Conference on Human Factors in Computing Systems - Proceedings*. https://doi.org/10.1145/3290605.3300677

Zimmerman, M. (2018). *Teaching AI: Exploring new frontiers for learning*. International Society for Technology in Education.

APPENDIX

https://docs.google.com/document/d/1F7mclwYP0sYj3T9Fg9IkAmG6SBkN4Bt2uIxISLCLJtc/edit?usp=sharing