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Integrating artificial intelligence into science lessons: teachers' experiences and views

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Abstract

Background In the midst of digital transformation, schools are transforming their classrooms as they prepare students for a world increasingly automated by new technologies, including artificial intelligence (AI). During curricular implementation, it has not made sense to teachers to teach AI as a stand-alone subject as it is not a traditional discipline in schools. As such, subject matter teachers may need to take on the responsibility of integrating AI content into discipline-based lessons to help students make connections and see its relevance rather than present AI as separate content. This paper reports on a study that piloted a new lesson package in science classrooms to introduce students to the idea of AI. Specifically, the AI-integrated science lesson package, designed by the research team, provided an extended activity that used the same context as an existing lesson activity. Three science teachers from different schools piloted the lesson package with small groups of students and provided feedback on the materials and implementation.

Findings The findings revealed the teachers' perceptions of integrating AI into science lessons in terms of the connection between AI and science, challenges when implementing the AI lesson package and recommendations on improvements. First, the teachers perceived that AI and science have similarities in developing accurate models with quality data and using simplified reasoning, while they thought that AI and science play complementary roles when solving scientific problems. Second, the teachers thought that the biggest challenge in implementing the lesson package was a lack of confidence in content mastery, while the package would be challenging to get buy-in from teachers regarding curriculum adaptation and targeting the appropriate audience. Considering these challenges, they recommended that comprehensive AI resources be provided to teachers, while this package can be employed for science enrichment programs after-school.

Conclusions The study has implications for curriculum writers who design lesson packages that introduce AI in science classrooms and for science teachers who wish to contribute to the development of AI literacy for teachers and the extension of the range of school science and STEM to students.

Keywords Artificial intelligence (AI), Teacher perception, AI-integrated lessons, Science lessons

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Introduction

The world is currently undergoing what Schwab (2017) has called the Fourth Industrial Revolution, which has been characterized by increased connectivity and automation propagated by technologies including artificial intelligence (AI), machine learning (ML), and digital fabrication. In hidden or explicit forms, many lives are now shaped by AI. For instance, AI has been embedded in search engines of online consumer platforms and email (e.g., Google and Yahoo) to market items and promote consumerism (Verma et al., 2021). AI has also been applied to agriculture, education, finance, security, science, healthcare, traffic control, crime control, and so on (OECD, 2019). While we have become aware of the pervasiveness of AI in shaping human lives, we asked ourselves as STEM educators and teacher educators about our role in empowering learners with the relevant knowledge and skills about AI to thrive in society as literate citizens.

Many scholars and policymakers have argued for schools and societies to place greater emphasis on developing the AI literacies of students. The report *Talent for the Future: AI Education for K-12 in Canada and South Korea* (Asia Pacific Foundation of Canada et al., 2021) has called for the government to make tangible investments in AI education for K-12 students. Such education opportunities should be made equal and be of good quality. Further, AI ethics should form the core and centerpiece of the curriculum (Akgun & Greenhow, 2021). For such implementation to be successful, teachers must be enrolled to assist in the materialization of such an endeavor. In South Korea, the Ministry of Education has announced a plan to train 5000 AI-literate teachers through professional development (PD) by 2024 and also promised to develop accredited AI textbooks for elementary schools.

As the implementing agents in direct interaction with students, teachers hold a critical role in achieving the goal of fostering AI literacy among students within their teaching subjects (Casal-Otero et al., 2023). However, it seems a tall order for teachers to be able to become AI-literate educators especially when most of them are not trained in AI (Sanusi et al., 2022) and their teaching duties are already very intense. This may be because it necessitates significant effort for them to integrate AI instruction into their subjects (Lin & Van Brummelen, 2021). History in education reform has informed us about the challenges in onboarding teachers in the implementation of any new curriculum that has occurred for many reasons including time, assessment stress, lack of knowledge in the new topic, and so on (Teo, 2019). It implies that a substantial amount of systemic effort would have to be provided to teachers to support their PD in AI literacy. This entails working within existing structures through adjustments rather than revamps that are disruptive to teachers' work. With this in mind, we embarked on a study to support Singapore science teachers in enacting a lesson package that introduces the idea of AI to students so that they can become more aware of it. This paper reports on the teachers' experiences with and perspectives on the student learning that took place during the implementation of a curriculum that introduced AI with science. As science teachers, an emergent conversation that came up during the post-implementation dialogue was the relationship between AI and science. Recommendations were provided by the teachers to improve the lesson package for adoption or adaptation by other teachers.

The context of this study

Unlike other education systems such as China, Canada, and South Korea, Singapore has only begun to take small steps in introducing AI to students. Such efforts are typically undertaken by external organizations and industries such as AI Singapore (AISG)®, Google and Amazon web services. For instance, the AI4K® program was developed by AISG to introduce AI literacy to upper primary school children aged 10 to 12. AISG also offers student outreach programs for students in secondary schools and post-secondary institutions. At the time of this study, there were very few existing curricula led by school teachers in regular discipline lessons in Singapore. Hence, AI has often been perceived as an isolated topic pursued by students with special interest in the field. The implication of this is that AI will be taken up by specific groups of students rather than all students. This could potentially go against the grain of efforts that call for equal accessibility to AI literacy for all students. This study recognizes the limitations of such efforts and purposefully identifies a space within the regular school curriculum to implement the AI-integrated science lesson package that we have developed.

The AI-integrated science lesson package was piloted by three science teachers who taught Grade 7 (aged 12 and 13) students in 2022. In Grades 7 and 8 (lower secondary levels) in Singapore, students in the Express and Normal Academic streams (Tan et al., 2016) experience the same lower secondary science (LSS) curriculum while students in the Normal Technical stream will experience a different LSS curriculum. The LSS curriculum at this time was aligned to the revised Singapore science curriculum framework (Ministry of Education, 2020), which underscores the importance of the practices of science in the teaching and learning of the discipline. Scientific practices encapsulate understanding the nature of scientific knowledge, demonstrating ways of thinking of doing science, and relating science, technology, society, and the environment.

The LSS curriculum is divided into four themes: diversity, models, interactions, and systems (Ministry of Education, 2020). Each theme is accompanied with a set of textbooks and activity books covering a few science topics. The activity books comprise practice questions related to the topic units and the key essential takeaways for each theme. The last unit of an activity book is an integrative activity that integrates all the units and the key essential takeaways of the theme.

In particular, in this study we have decided to weave in content about AI in the integrative activity of the activity book on models among four themes. The four topics taught under the theme of models are the particulate nature of matter, atomic structure, the ray model of light, and cells as the basic units of life. The three essential takeaways about models are (1) models are simplified representations of phenomena that provide a physical, conceptual, or mathematical perception of reality; (2) models are constructed to explain phenomena; and (3) models can be used to make predictions.

We approached AISG to collaborate on this study. Specifically, we adapted one set of resources that they had developed to introduce AI using the context of space data. This topic is related to an integrative activity that explores the idea of habitation on Mars. Hence, the AI resource serves as an extension to the existing integrative activity (see Fig. 1). The research team developed the lesson package—the structure and details is shown in Table 2 in the Methodology section—and shared it with three science teachers from different schools who participated as research subjects.

Research questions

The overarching research question and specific research questions addressed in this study are: What were the science teachers' experiences and views in integrating AI content into their lessons?

1. How did the teachers perceive the relationship between AI and science in the AI lesson package?
2. What did the teachers identify as challenges in implementing AI-integrated science lessons?
3. What did the teachers recommend for the improvement of the AI-integrated science lesson package and why?

This study aims to examine the three science teachers' views and experiences in piloting the AI lesson package that we had developed focused on ML, a part of AI. The curriculum was an extension to a unit in the science activity book used by the teachers in their Grade 7

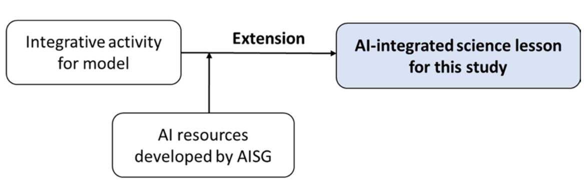


Fig. 1 AI-integrated science lesson

lower secondary science lessons, with the theme focused on scientific models and modeling practices. We were interested in investigating the relationship that teachers perceive between AI and science while enacting the curriculum. When science teachers could make connections between AI and science, they would be more willing to integrate AI into their science curriculum (Kim, 2022). However, teacher buy-in to curriculum change could be facilitated if they know in advance challenges to expect and actively engage them in the design and development of the curriculum. Hence, we elicited responses from teachers about the challenges they have faced in implementing the AI curriculum and sought their views on improvements. These comments are incorporated into the revision of the curriculum for future implementation.

Theoretical background

How to integrate AI into the curriculum: designing an AI-integrated curriculum

Integrating AI into a curriculum involves curriculum designers deciding what and how to teach it in the curriculum (Akram et al., 2022; Yang, 2022). We have categorized two design consideration aspects for AI-integration curricula derived from prior literature: orientation, which relates to the selection of teaching content, and pedagogy, which involves factors such as teaching strategies and materials. Table 1 illustrates the orientations and pedagogies used for integrating AI into a curriculum in this study.

AI-integrated curricula in previous literature can be categorized into three orientations: AI-focused, discipline-focused, or a combination of both AI and a specific discipline. First, AI-focused orientation aims to foster students' AI literacy. In schools, it can be a stand-alone subject—such as an elective course—or a separate part of existing disciplines, such as information technology, implying that there is no integration with other subjects. AI literacy is defined as "a set of competencies that enables individuals to critically evaluate AI technologies; communicate and collaborate effectively with AI; and use AI as a tool online, at home, and in the workplace" (Long

Table 1 Designing AI-integrated curricula

	Curriculum integration design
Orientation (content)	– AI-focused orientation – Discipline-focused orientation – Integrated orientation of both fields
Pedagogy	– Collaborative learning, hands-on activity, inquiry-based learning – Tools for teaching AI appropriate to instructional objectives and students' developmental stages

Table 2 The structure of the AI-integrated science lesson

The flow of the lesson (segments)	Descriptions
(1) Pre-lesson video primers	– Introduce the concept of AI – Provide an overview of the machine learning (ML) cycle
(2) Recapitulation of key science ideas	– Recap key science ideas taught in Grade 7 science, including diversity, models, and scientific methods
(3) Linking the key science ideas to key AI ideas	– Do a trigger activity using "Quick, Draw!", which showcases the predictive abilities of ML – Engage in an activity to understand how machines and humans learn
(4) Developing an AI predictive model using Orange program	– Pose the scientific problem of developing a model that enables determination of conditions for deploying solar panels on Mars to harness solar energy – Build a predictive model involving big data based on ML algorithm using the Orange software program

& Magerko, 2020, p. 598). The AI-focused orientation is aimed at designing a curriculum that focuses on educating students to enhance their AI literacy, which includes aspects such as what AI is, how AI works, AI applications, AI tools, and the social impact of AI (Kim et al., 2021; Touretzky et al., 2019).

The second orientation is discipline-focused. This orientation involves teaching AI within the context of existing disciplines such as mathematics and science. Components of AI taught in this discipline are chosen and arranged based on the themes or core ideas of these disciplines. According to the framework of discipline integration levels by Vasquez et al. (2013), this orientation corresponds to multidisciplinary integration, which means that students learn the concepts and skills of each discipline separately but within a relevant theme, or interdisciplinary integration, where students can deepen knowledge and skills from two or more disciplines (Casal-Otero et al., 2023). This approach could help students understand the connections between the two disciplines while also fostering AI literacy. For instance, Shin and Shin (2021) created an AI-integrated program for fourth-grade students using Google's Teachable Machine as an AI tool in a plant-classification inquiry project. In this program, students learned both how the Teachable Machine works with the data they input, which relates to AI components, and plant-classification and criteria for the classification activities, which are components of science. Considering that classification is a shared theme of AI and science in this program, students learned about the AI tool in the context of science education. In this orientation, students could learn relevant ideas, skills, and attitudes related to AI that helped enhance their understanding of existing disciplines.

The last orientation focuses on designing curricula that apply AI knowledge and skills from existing disciplines to solving real-life problems. This can be considered a transdisciplinary integration, which is the highest level of integration (Vasquez et al, 2013), and involves a genuine context for solving problems relevant to our daily lives. Through these integrated projects, students can apply their knowledge and skills from more than two disciplines in a contextual manner, thereby refining their learning experiences (English, 2016). For instance, one of the projects in Akram et al. (2022) involved developing a contact tracing application using a breadth-first search algorithm, which is a tree data structure for exploring a graph level by level beginning with an initial point and checking all connections (see Beamer et al., 2012), to facilitate decision-making around self-quarantine during the COVID-19 pandemic. This project set integrated goals of competency, interest, and career aspirations to be achieved through an AI-infused science problem-solving activity. The development of a recognition model using Google's Teachable Machine to classify recycling materials (Martins et al., 2023) also exemplifies this orientation.

In terms of pedagogy, one of the main issues in discussing instructional approaches for AI education is how to deal with the complex and abstract nature of AI knowledge and concepts (Zhou et al., 2020). Due to the nature of AI content, this issue has been significantly discussed with reference to various instructional approaches such as collaborative learning, hands-on activity, and inquiry-based learning (Ng et al., 2021; Sakulkueakulsuk et al., 2018; Sintov et al., 2017), which can share similar pedagogical approaches to subject education. For example, social interaction and collaborative group activities have been emphasized to engage students in ML activities (Sperling & Lickerman, 2012; Vartiainen et al., 2020) and science inquiry activities (Wan et al., 2020). Hands-on activities have been reported to be effective in teaching abstract AI concepts to promote active learners when they consider the stages of students' development of concrete thinking (Williams et al., 2019). Similarly, to foster students' engagement, it has been shown to be effective for students to deal with concrete or relevant data created in their sociocultural context (Sakulkueakulsuk et al., 2018; Van Brummelen et al., 2021).

Meanwhile, determining which tools provide an appropriate degree of student involvement in managing AI processes is another critical issue of pedagogy in AI education (Zhou et al., 2020). Two approaches to address this issue have been considered so far that are contingent upon instructional objectives and students' developmental stages. The first approach focuses mainly on a problem-solving process based on AI-based solutions (Akram et al., 2022; Van Brummelen et al., 2021). This approach involves the technical use of AI skills in an AI-integrated activity using simplified programming or block coding programs that allow young students to experience and use data modeling easily (Charters, 2003; Lane, 2021). The second approach concentrates on teaching AI concepts and knowledge themselves (Hitron et al., 2019). Specific pedagogical strategies have been developed to unpack the complex process, akin to a black box, to help learners understand how ML works (Wan et al., 2020; Williams et al., 2019). There has been no definitive answer as to which tool and approach are better, and they should be determined depending on the objectives, target students, and curricular context.

Given that the curriculum orientations established by teachers are a hidden force that determines curriculum content and teaching method (Cheung, 2000), an orientation to form an AI-integrated curriculum can be an essential issue in determining a curriculum's detailed directions, including curriculum content and pedagogy. In the context of this study, it is essential to consistently establish and clarify the orientation and pedagogy of the AI-integrated curriculum. The AI-integrated lessons in this study focused on a discipline-focused orientation to teach AI in the context of science lessons with the intent of affording students' opportunities to learn and practice the concept of a model, which overlaps the two fields of AI and science. Concretely, in the aspect of curriculum content, students learned the similarities and differences between AI and science in developing a more accurate model. In the aspect of pedagogy, students were guided to use AI skills technically in their scientific problem-solving processes. This research context was intended to improve understanding of the decisive impact of lesson implementation on the formation of teachers' perceptions of AI-integrated science classes, which has rarely been examined, as we seek to understand from their perspective and make curricular adaptation successful.

Implementing an AI-integrated curriculum: considerations and challenges

As the uses of AI in education increase, various challenges that need to be considered for AI lesson implementation have been reported. The practical considerations and challenges reported in previous literature can be summarized in terms of teachers' instructional strategies, professionalism, and support for AI-integrated lessons.

The first challenge is selecting a suitable learning program or activity as one of the key instructional strategies for AI programming or developing AI models appropriate to students' levels (Van Brummelen et al., 2021). Researchers have developed and applied various AI activities, including physical, web-based, and unplugged activities (Zhou et al., 2020). In web-based activities, widely used AI platforms, such as Teachable machine, ML for Kids (Lane, 2021), and AI Programming with eCraft2Learn (Kahn & Winters, 2018), have been generally adopted in AI lessons considering target students' ages, developmental stages and lesson goals (Williams et al., 2019).

Another instructional consideration is how to evaluate and measure student learning outcomes in AI-integrated lessons. Teachers can create assessment standards and evaluate the overall process of problem-solving with AI activities, such as using a checklist and teacher observation of peer interaction, presentation, and discussion (Kim et al., 2021). Another way to efficiently measure student outcomes in AI-integrated activities that have been discussed is to systematically create a measurement mechanism to directly calculate the similarity or cohesion of data modeling created by students and offer automatic feedback for students (Wan et al., 2020). Either way, teachers need to evaluate students' processes and outcomes in connection with the goals of AI-integrated lessons.

The more fundamental challenge in dealing with the above considerations is fostering teachers' professionalism and self-efficacy for AI-integrated lessons. Teachers need to have sufficient knowledge related to AI tools and technologies so that they can understand and effectively use the educational roles of AI (Celik, 2023). However, if teachers' preconceptions about AI remain on an abstract and rudimentary level and they have difficulties using technical terms, they will not have skills sufficient for teaching AI (Lindner & Berges, 2020). Teachers themselves have also been reported to perceive that they did not have enough knowledge about AI in designing and implementing AI-integrated lessons (Chounta et al., 2022; Sakulkueakulsuk et al., 2018). Therefore, increasing teachers' professionalism and efficacy in AI knowledge, skills, and tools is the most urgent and fundamental task.

Dealing with this urgent task, a new framework of AI-technological pedagogical and content knowledge (AI-TPACK) has been suggested to re-explore the relationship of teachers' professionalism in technology, teaching methods, and subject content in the AI context (Zhang, 2021). Zhang (2021) argued that in isolation, AI-technological knowledge (TK), AI-pedagogical knowledge (PK), and AI-content knowledge (CK) are all insufficient to help teachers apply AI technologies effectively in their lessons. AI-TPACK knowledge, however, as the combination of the three elements, may be the most practical knowledge base for teachers to integrate AI into classroom teaching. The various perceptions and concrete teaching cases of teachers who integrated AI into science classes in this study can be valuable as basic data for exploring the development paths of teachers' AI-TPACK.

Even with expertise, however, teachers face several practical difficulties in designing, managing, and implementing AI-integrated lessons. Teachers have been reported to perceive that they needed to be supported with more time and appropriate resources or activities for AI-integrated lessons, even if they were eager to implement AI lessons (Sakulkueakulsuk et al, 2018). As one of the ways to support teachers, a guidance chart has been developed and provided to help teachers efficiently find suitable resources for their students (Zhou et al., 2020). More supportive ways and practical resources like this need to be considered and provided for teachers.

Given the considerations and challenges described above, we developed and provided an instructional package as a structured AI-integrated science lesson that can be adopted for an enrichment program after-school. The target lessons developed in this study were AI-integrated science lessons for Grade 7 students. The various perceptions and concrete teaching cases of the participant teachers who integrated AI into science classes in this study were then holistically investigated with a focus on the relationships among science content, science teaching, and AI technologies. The practical cases in this study can be valuable as basic data for exploring the concrete ways of teaching AI-integrated lessons and the development paths of teachers' professionalism in AI-TPACK. We will illustrate more concrete considerations in the Methodology section.

Methodology

This study adopted an instrumental case study design (Stake, 2000) to address the overarching research question: *What were the science teachers' experiences and views in integrating AI content into their lessons?* Considering the contextual nature of the case study, this study aimed to draw insights into approaches to integrating AI into science lessons based on examining a case of teachers' teaching practices and their reflections on their practices rather than making a universal claim. For this case study, we provided a "thick description" (Denzin, 2002) to illustrate how the teachers perceived the relationship between AI and science, the challenges of implementing AI-integrated science lessons, and recommendations on improvements based on qualitative analysis.

Research participants and data analytic processing

The three science teachers, all in different secondary schools, who will be referred to by their pseudonyms, Tom, Jennifer, and Chris, and their 37 students (10, 21, and 6 students, respectively) participated in the project. The teachers were recruited as personal contacts of the authors. Although the science teachers each had less than five years of experience teaching science in schools and had not been trained in teaching AI, they were interested in this project to learn more about AI-integrated science lessons. All of them taught lower secondary science for grade 7. Additionally, Tom and Jennifer instructed chemistry for grades 9 and 10, while Chris covered physics for those grades. The students joined voluntarily, with parental agreement, after receiving the recruitment advertisement for the project.

The involvement of the research participants was carried out in three stages: (1) an introduction session for the teachers as a PD session; (2) the implementation of the AI-integrated science lesson package; and (3) a reflection session with the three teachers. In the introduction session, the research team provided a detailed explanation of the developed lesson package to the teachers. The introduction session focused on the structure of the lesson package: an overview of the concepts involved in the lesson was given, including the key ideas of ML and a brief introduction on how to use the ML program that will be used in the lessons rather than a systematic elaboration to provide a more detailed understanding of ML concepts. Overall, this PD was conducted with TK, PK, and CK within the context of the lesson structure. After the introduction session, the 3-h AI-integrated science lesson, excluding recess, was implemented after school in the three different schools. The implementations of the three lessons were observed by the authors and audio- and video-recorded and transcribed. The researchers' field notes and students' worksheets were also collected as secondary resources to enrich the contextual understanding of what happened in the classrooms (Merriam, 1998). After the lesson implementations, the research team held separate reflection sessions with two teachers together (Jennifer and Chris) first and then with the remaining teacher (Tom). The initial plan was for all three teachers to be guided together using the focus-group discussion method (Nyumba et al., 2018); however, because Tom was unable to join the session, he had a separate session with the research team with a focus on the raised issues in the first reflection session. The reflection sessions were conducted following semi-structured questions, which were given to the teachers in advance: What do you think are the similarities and differences between AI and science? What do you think is the relationship between AI and science? What were the most challenging components to teach? What parts were difficult to make sense of? What are your comments on improving this package? The sessions were audio-recorded and transcribed.

The corpus of the qualitative data was analyzed using Margot and Kettler's (2019) literature review for teachers' perceptions of STEM education as a framework, enabling us to purposefully investigate the teachers' perception of the AI-integrated science lesson. The framework comprised three parts: (1) teachers' views about the connections between science and AI; (2) the challenges of the AI-integrated science lesson package; and (3) recommendations on improvements for future curriculum adoption and implementation. These were then transformed into the three research questions. With these three targeted objects, the data were analyzed using the constant comparison method (Merriam, 1998). We began by first analyzing the reflection session data to find emerging preliminary patterns of the teachers' perceptions of the three focuses. We also incorporated the other data, including lesson recordings, lesson observations and the students' worksheets so that we could compare and adjust continuously to accommodate new insights. The research team iteratively performed the analysis until an agreement was reached.

Structure of the AI-integrated science lesson package and developmental considerations

Given the discipline-focused orientation of this study and its focus on pedagogies for AI integration, this AI-integrated science lesson package (see Table 2) was developed with four segments that were designed with several key considerations to ensure its effectiveness and accessibility to the targeted research participants: the three science teachers and their Grade 7 students. (1) In the first segment, students are expected to be able to come into the lesson with a more fundamental understanding of AI, which would help with the development of lesson ideas during the lesson proper. To accomplish this, two videos created by AISG were selected: one provides a brief introduction to what AI is and a showcase of some common examples of AI, while the other gives an overview of the ML cycle with reference to an analogy of cooking (see Fig. 2). (2) The second segment of the lesson package is a set of slides aimed at activating students' prior knowledge about science ideas and themes that they have learnt in LSS. This segment aims to elicit three key ideas from students: the appreciation of diversity through categorization, the concept of models as representations that can be improved upon, and an understanding of science as a systematic endeavor that occurs via scientific methods. (3) In the third segment, students are introduced to ML through "Quick, Draw!", an online game developed by Google that showcases the predictive power of ML.

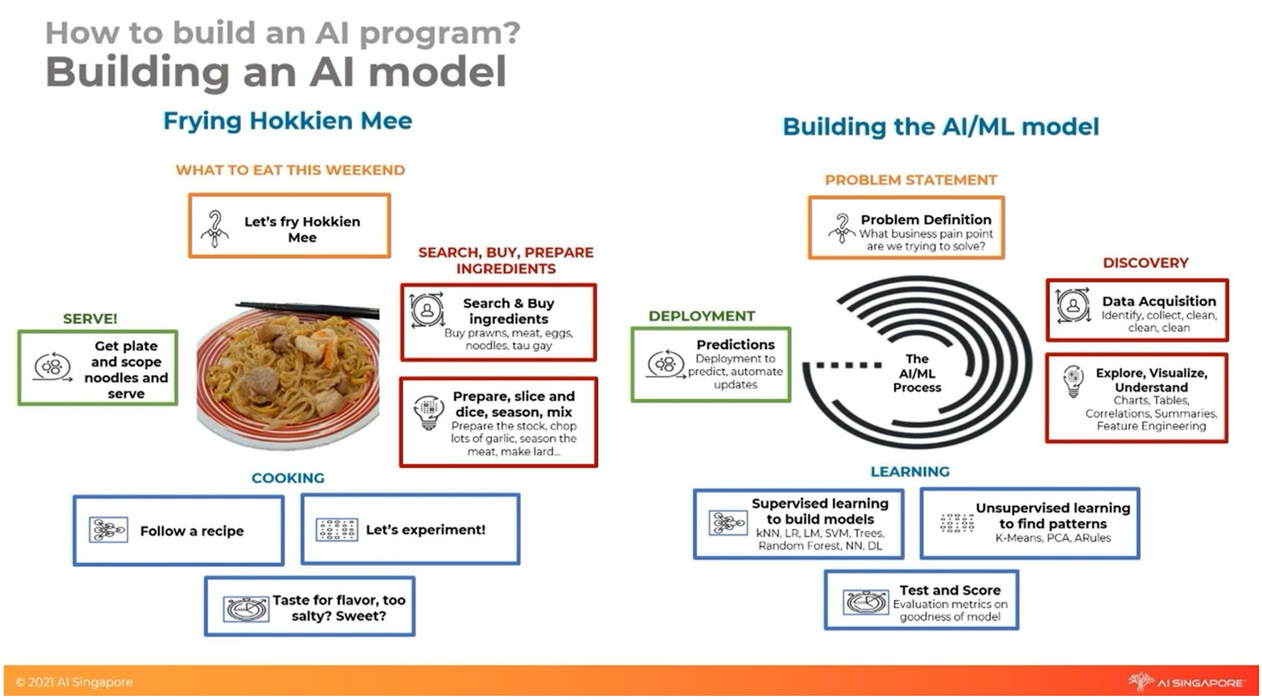


Fig. 2 Analogy of cooking and ML model generated by AISG

Students draw an assigned object while the program guesses what is being drawn, exposing them to the predictive abilities of ML. Afterward, students engage in an activity that helps them understand how they learn, which connects to the idea of how machines learn. In this activity, the teacher guides students to draw a square, prompting the students to reflect on how humans recognize the features of squares and on how the evolution of their thinking is analogous to the ML cycle. (4) In the final segment, students are presented with a scenario where the Mars Rover requires electrical energy. They are tasked with developing a model that can identify how given values of variables can predict either high or low solar radiation so that energy can be harnessed through deploying solar panels. There are various variables that may or may not have an impact on the energy collection efficiency on Mars, with 32,000 data items constituting big data sets. To solve this scientific problem, students build their own predictive model using the software Orange (Demšar et al., 2013) after being introduced to the ML cycle and drawing links to scientific methods. This Orange program provides a technological platform that facilitates the generation of predictive models using big data. This program was chosen by AISG to provide general education in AI for students, and we also considered the Orange program to have a level appropriate to Grade 7 students. The hands-on activity is an adaptation of an existing exercise that showcases the different stages of the ML cycle. Upon completion, students reflect on the lesson's content by articulating their perceptions of how using AI can benefit the study of science and how the study of science can help improve AI.

We paid close attention to the design of the lesson package for this AI-integrated science lesson in terms of both the design consideration framework (see Table 1) and the AI-TPACK framework. First, the package aimed to be simple yet effective and accessible to Grade 7 students while also developing a relational understanding of AI processes. For example, it used a simple definition of AI, referring to AI as having the ability to sense, reason, act, and adapt. Second, the lesson package was built on existing AISG resources but needed to be adapted to better fit the LSS context, including modifying the Mars Rover activity to include more scientific reasoning and discussion. For example, an existing AISG activity involves a data set with the five variables of humidity, pressure, temperature, wind direction, and wind speed on Mars. However, we deliberately split this data set into five sets, with each set missing a different one of the variables but containing the other four, for students to have an opportunity to determine which data set would be most appropriate for training the machine to develop the most accurate predictive model. Considering that most students did not know how to develop a model using the Orange software, we provided steps for them to follow and the rationale behind the steps. We hope that this would allow students to be able to evaluate the best predictive efficacy with a showcase of the predictive ability on an unknown data set in the package. Third, a hands-on activity utilizing the Orange software, designed to solve a scientific problem using an inquiry-based approach, was conducted in a group setting to promote collaborative learning. Last, the lesson package was explicitly integrated with the LSS syllabus and curriculum framework to gain teacher buy-in, with the second and third segments critical in helping teachers draw links between what was taught in LSS and what would be taught in this lesson package.

Findings

This study was conducted with the intention of identifying the teachers' experiences and views based on the introduction session, implementation of the developed AI lesson package, and reflection session. The findings will be illustrated with the teachers' reflections and the relevant excerpts from their lesson implementations in responding to the research questions accordingly, focusing on (1) the teachers' perceptions about the relationship (i.e., similarities and differences) between AI and science; (2) the challenges they faced in executing the lesson package; and (3) their recommendations for the improvement of the package.

RQ1: How did the teachers perceive the relationship between AI and science in the AI lesson package?

Similarities between AI and science as a starting point to teach

The teachers thought that the AI lesson package was a reasonable approach that allowed the students to learn about AI as a tool for doing science based on the similarities between AI and science, such as developing a more accurate model with relevant data and using simplified reasoning. This can be a starting point to teach AI and science together as a discipline-focused approach.

Developing a more accurate model through relevant data The teachers viewed developing a model based on the relevant data as a similarity between AI and science, although AI and science had different aspects and purposes. The differences will be illustrated in the next section. In particular, they also thought that both AI and science aim to refine a model to be more accurate by adding further quality relevant data. This perception came as a result of the reflection and was not the initial idea of all teachers. In the beginning, Jennifer and Tom were not convinced of the similarity between AI and science of the development of models. Jennifer noted that she did not emphasize this aspect of the nature of science in her previous teaching but rather taught how to build models in science using scientific methods as she answered the question about the relationship between AI and science in the reflection below.

R1: What do you think is the relationship between AI and science?

Jennifer: Actually, I thought that it was a bit difficult to find the link between AI and science. Yeah, personally I was not very convinced because I think. … like for example, the iterative approach kind of modifies models as they come along, but. As a teacher of the LSS syllabus, I do not find myself emphasizing all these points.

(Excerpt 1 from the Reflection, Jennifer)

However, she ended up incorporating the idea of the iterative process for refining models more accurately with data as the connection between AI and science in the reflection.

R2: So just to clarify, you are saying that AI involves the building of models and science also Involves it as well?

Jennifer: … When we collect more and more data, we refine the model and make the prediction much more accurate than it originally was, and that's such a more direct way of, you know, just showing to the students that. When we collect more data, we collect more accurate data with the development technology. It helps scientists also refine their hypothesis, refine their models of the real world.

R2: I think that is a good point. So, in other words, the kids will also get to see that whether you're doing the AI work to make a prediction or you're doing scientific work, both involve working with data and the sample size of the data matters.

Jennifer: And the quality of the data matters.

(Excerpt 2 from the Reflection, Jennifer)

She considered both the data and the quality of data, which is crucially important in developing models. She taught this refining model process by providing further data to her students. Excerpt 3 below was what she mentioned in the closing phase of her lesson.

Jennifer: You see whether it's correct or not, then after that you will change update your model, improve your model so we learn about AI. … Then after that we thought about OK, how do we build an AI system through the machine learning cycle? We identify the problem, we collect data in this case in this lesson. Because of limited time, I gave you the problem and the data.

(Excerpt 3 from Jennifer's lesson from 2:41:53 to 2:42:22)

Similar to Jennifer, after his involvement in this project, Tom found that the link between AI and science requires a basic understanding of AI to prepare and execute the lesson package. He was able to extend his understanding of AI through the lesson plan, the videos provided for the lesson, and the readings, although this understanding would not be sufficient to use the larger range and types of AI. Excerpt 4 below shows his thought changes on the relationship between AI and science.

R1: What do you think is the relationship between AI and science?

Tom: Actually, I viewed AI as quite separate from AI and science. Yeah, but it's only after I got involved and then we had the Zoom call the other time and then I went to read up more based on the lesson plans and the attached few videos and websites for us to go and visit. And then it's only after I did all that reading up, then I realized. Actually, there's the link, and for us as a teacher, the most obvious link is to the team of models. ... You put some data in. It creates a model, and that model can be used to solve problems.

(Excerpt 4 from the Reflection, Tom)

The cases of Jennifer and Tom indicate that we could draw the two possible conditions for recognizing the development of models as a link between AI and science: (1) model-building as a scientific enterprise and (2) a basic understanding of AI, in particular the mechanism of ML. Awareness of these two conditions will enable teachers to be at a starting point for teaching integration of AI and science as a science-focused orientation approach. Since science has various forms of practice, it is necessary to explicitly indicate what aspects of science can be linked to involve AI components as an intersectional area of AI and science. Kim (2022) discussed the similarities between AI and science in terms of their nature of epistemic processes. Although there are different epistemic aims—science traditionally focuses on knowledge claims while AI focuses on generating solutions and predictions—scientific methods allow for validation and improvement of the intellectual outcomes, such as models, in both AI and science. On the other hand, understanding the basics of AI is another essential prerequisite for teachers who want to employ this approach. Similar to Tom, science teachers generally tend not to have been trained to teach AI in science lessons. It may sound paradoxical since AI and science have different natures, but science teachers can start to teach AI in their lessons when they have an understanding of the similarity between AI and science from a science-focused orientation.

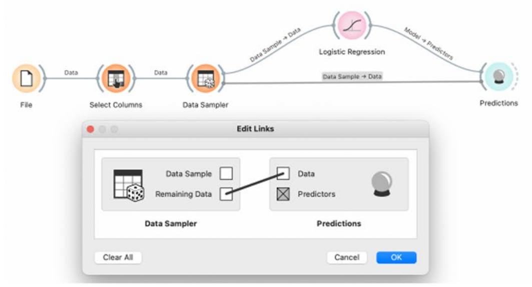
Using simplified reasoning purposefully (or necessarily) Practically and realistically, it was extremely difficult to teach the overall idea and complex mechanisms of AI to Grade 7 students, considering their expected understanding level of AI and the teachers' comprehension of the ML mechanism used in the lesson. Finding no other alternative, a simplified explanation of the reasoning of AI, or a "black box", was used in the implementation of the lesson that involved practicing ML using the Orange program. The statistical method for ML used in the lesson was logistic regression, which is generally not taught until high school. Although the lesson was developed this way, all the teachers seemed to be in agreement on this approach, which means that the idea of using simplified reasoning can be regarded as a commonality between AI and science that teachers can use in progressing the lesson purposefully. Excerpt 5 below shows Chris's awareness of teaching ML algorithms simply to the students, Jennifer's response to this matter in science classes, and R2's aligned example.

> *Chris: We don't actually teach them about how the algorithms work and what they do. … Quite honestly, I don't think students have the prerequisite knowledge—really have a deep understanding of what logistic regression is … as a matter of fact, they just have to do it, except that this AI program or this model that they're creating is learning, and that's the word that I use with the, like, you're feeding it more data, which is learning. Then at the end of it, it makes a prediction. …*
>
> *Jennifer: It's like a property of sciences. In science, we use a lot of maths, but we only use the results. … It's so there are a lot of black boxes, I read. I think in science, we do often adopt many tools that were developed by other branches of maths or physics, and we just simply take the solution, and we apply it. … I'm OK with that black box idea. … We don't really need to because it's just a tool, and I see the crux of the matter as this tool helps you to answer scientific problems. … we will just have to have faith right in the program that you know is actually able to deliver us support.*
>
> *R2: … We have many black boxes in our learning, right? For example, we bring students to the lab and ask them to use the readings. Do they even know how the biuret is calibrated? Why is it that we should write to two decimal places? … So, there's a black box in the design of operators as well, right?*

(Excerpt 5 from the Reflection, Chris and Jennifer)

As Jenifer and R2 mentioned, using simplified reasoning is a prevailing phenomenon in science classrooms. Science educators are used to focusing on particularly targeted concepts (Wittwer & Renkl, 2008) and may marginalize peripheral parts to simplify to help students solve problems purposefully. It may be related to reducing extraneous cognitive load in designing instructions (Sweller, 1994). According to the cognitive load theory, content, which is less relevant to the targeted concepts, can be learned with complex information when the need is raised (Pollock et al., 2002). This teaching practice also happened in the AI-integrated lesson of this study. Simplified reasoning was used in progressing through the steps of training the program as a scientific modeling method with a large amount of data to focus on developing a predictive model. The simplification of reasoning emerged similarly in the three lessons. Jennifer explained how the data were divided and used in creating a model and testing the model, referring to the guide instruction shown in Fig. 3. It was a brief idea of an ML algorithm, which was enough for the Grade 7 students. As shown in Fig. 4 and Excerpt 6, the students understood that 70% of the data were used to create a model, while the remaining 30% was used to test the trained model.

> *Teacher: What you guys just did with the computer program was … the computer program randomly selected 70% of the data in your Excel file and you used it to train. So, 70% of the data was used to create a model. Okay?*
>
> *Teacher: What's this 30% used for?*
>
> *S1: Prediction.*
>
> *Teacher: What prediction? Why is it that we cannot use all the data? Surely, if we use 100% of the data, it's better, right?*
>
> *Teacher: Because we just say the more data you give the program, then the more accurate the program will be. Why can't we use 100%?*
>
> *S2: Accuracy.*
>
> *Teacher: How do we know that the computer program is good?*
>
> *S3: Need a test?*
>
> *Teacher: Need a test? How are you going to test?*
>
> *S3: Use the 30% to test.*

<table>
<tr>
<td>10</td>
<td>Click on the "Data Sampler" widget and drag it towards the "Predictions" widget to connect them. Double click on the text displayed on the connector to open a window and connect the "Remaining Data" box on the left" to the "Data" box on the right. The text displayed on the connector should read "Remaining Data → Data".


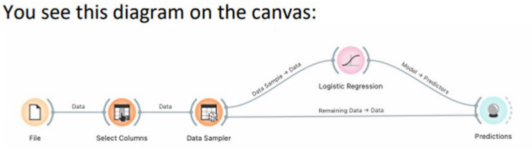
You see this diagram on the canvas:

</td>
<td>Earlier, only 70% of the data was used to train the model. The remaining 30% of data will be used to test how accurate your AI model is.</td>
</tr>
</table>

Fig. 3 A screenshot from the AI guide which is a material for the students. The middle column is the description of how to perform the step and the right-hand side column is for the reason for the steps

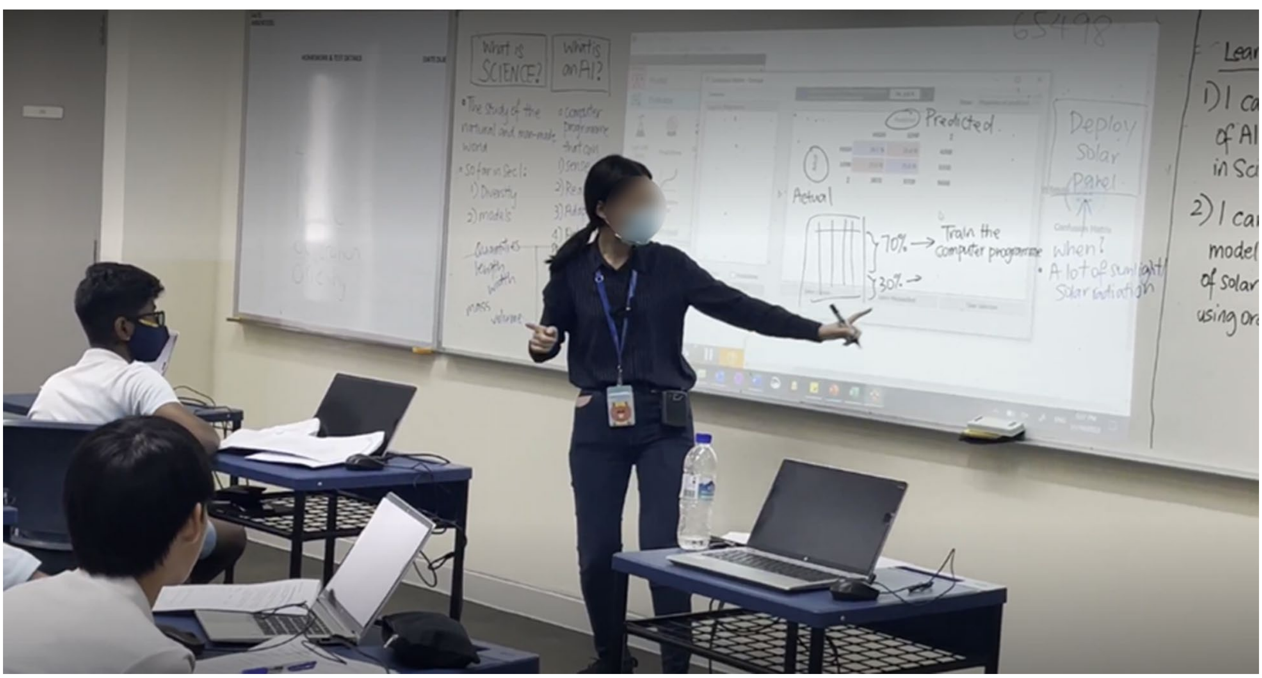


Fig. 4 A screenshot from the lesson when Jennifer was explaining the use of 70% of the data for training a model and the use of 30% of the data for testing the model

Teacher: Use the 30% to test, correct?

Ss: Yes.

Teacher: Ah, OK, so let me summarise.

(Excerpt 6 from Jennifer's lesson from 1:50:23 to 1:51:50, Note: S1, S2 and S3 indicate single student's responses while Ss means many students' responses.)

This pedagogical approach, which uses simplified reasoning, has been adopted to help younger students learn how AI works (e.g., Wan et al., 2020; Williams et al., 2019) and was also utilized in the lesson of this study. Through this lesson implementation, the teachers were given an opportunity to think about how science lessons also use simplified reasoning purposefully and necessarily. This does not mean that we should not teach more sophisticated ideas or have a discussion to help students to recognize the simplified reasoning in their learning activities. The important point is that simplified reasoning can be utilized in a particular context, as in the case of this study. If the students have more opportunities to discuss AI algorithms, they will be allowed to refine the simplified reasoning across different contexts. Science teachers' recognition of this similarity between AI and science can also be a starting point for integrating AI into science lessons.

Differences as a complementary role when teaching the AI-integrated science lesson

The three teachers also perceived that, based on their different natures within the lesson package, AI and science played complementary roles in providing both learning content and a context for that content. Science provided a context for the problem, which in this case was determining the proper conditions to obtain solar energy through the solar panels of the Mars Rover, while AI played a functional role in contributing to drawing a solution to solve the problem. Their thoughts on the different roles of AI and science were important in concretizing how to integrate AI into science lessons.

Science as a contextual understanding that enables judgment of data. The teachers thought that science could help them judge whether data or variables are useful and relevant or not, while AI cannot provide this function. This means that science still provides the focus for what is to be achieved, while AI serves as a supplementary tool in that endeavor. This was a major difference between AI and science in the lesson package. In the reflection, Jennifer and Chris shared their thoughts about science providing a contextual understanding that enables judgment of the usefulness of the data (Excerpt 7).

> *Jennifer: I wanted to spend more time discussing how the data set produced the best, the most accurate model and it's going to do scientific variables. So, I guess machine learning or AI, from my current understanding, is that there is so much data. ... If actually, we can train a computer to do everything right. So why do we still need scientists? Scientists' jobs are really to help us to see the data that's useful and the data that are not. ... You know, which are the causes that will lead to this final effect, because we study physics and other sciences. I think that's the value of the scientific model. ... and AI is a tool, right, to help us to supplement that, so, without this kind of basic understanding [of science], it can be not sophisticated and lacks cause-and-effect understanding.*
>
> *Chris: ... Scientists actually make decisions about, you know, what is important, what is relevant. For example, I could bring in a variable that has nothing to do with. It's not going to help the model become better. It might actually make it worse, right? Yeah, so if you want to go in that direction then it might be useful to introduce something like another data set with data that's actually variables that are not important or variables that don't actually help the model make better predictions. And then get students to think about why that's the case.*

(Excerpt 7 from the Reflection, Chris and Jennifer)

The teachers' perception of science's role can be interpreted as providing the meaning of the variables, which in this study was a contextual understanding of the proper conditions for unfolding the solar panels to get solar energy. An example image of Mars Rover, which has foldable solar panels, was shown in Jennifer's lesson (see Fig. 5). For example, the data of the lesson included many variables such as humidity, wind direction, wind speed, air pressure, and temperature that were provided for creating a predictive model. However, if they did not have a relevant scientific understanding, the numbers in the data set did not provide any meaningful information even when the students trained the program using the data set. The meanings of the numbers were only able to be understood by making links between the numbers in the variables and relevant scientific knowledge guided by the teachers. Based on this contextual understanding, the students could roughly estimate the usefulness of each variable, referring to the result of the model test to solve the scientific problem they were given. This is an important consideration in terms of the roles of AI and science when integrating AI into science lessons.

AI as a platform that makes a complex flow simpler with visualizations. AI, in particular ML, focuses on developing algorithms or predictive models through identifying patterns by input data (Jordan & Mitchell, 2015). Thus, the meaning of AI in the lesson package should be related to the use of the program that enables the students to develop a predictive model. The Orange program used in the package provided the technological platform used in the lesson for creating a model and testing it with a data set consisting of 32,000 items. The practice of using this program involved the use of logistic

Fig. 5 An example of the image of Mars Rover which has foldable solar panels shown in Jennifer's lesson

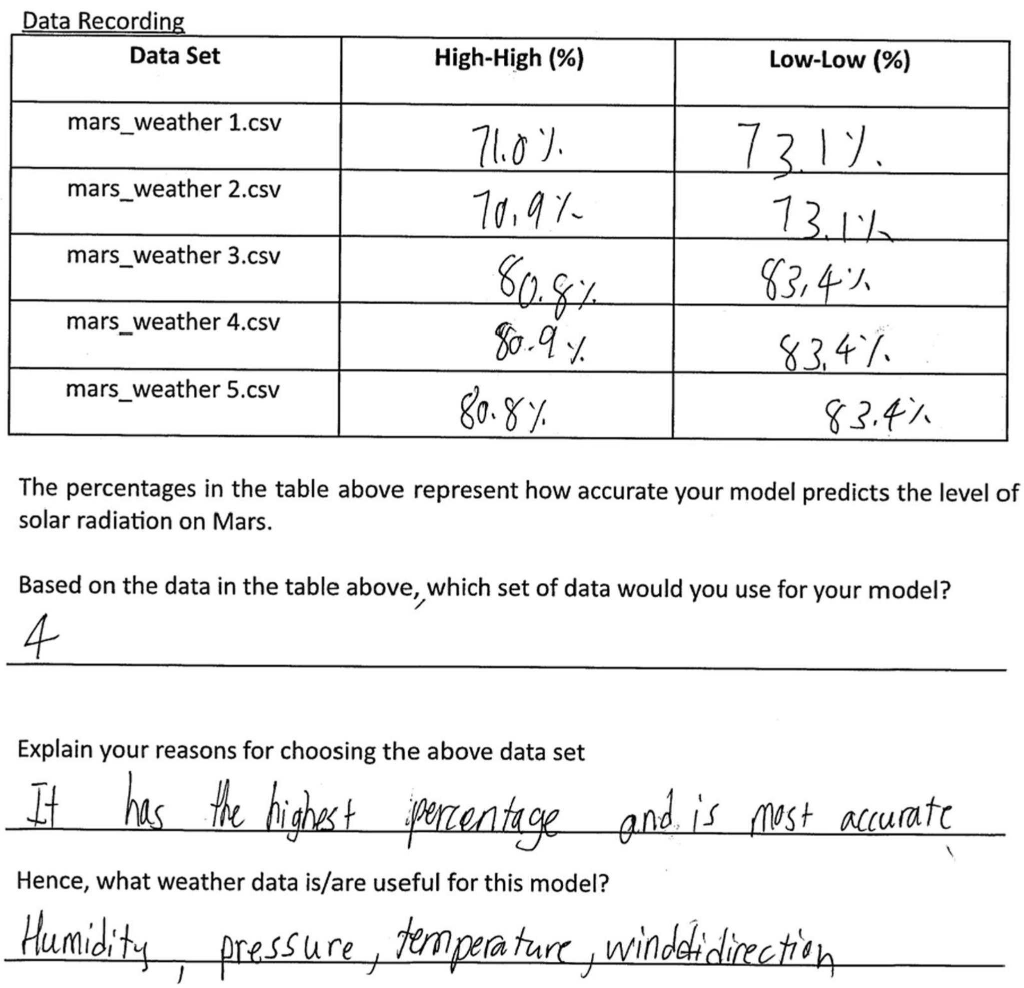
regression as a modeling method that requires an understanding of the flow of this complex process. In fact, understanding this complex ML algorithm precisely was difficult not only for the students but also for the teachers, which will be discussed in the next section on teachers' challenges. Although it was a challenge to understand the AI algorithm used in the lesson, most students and teachers seemed to have understood an overview of the AI algorithm, including training the program for creating a predictive model and testing it to solve the problem. Most students (32 out of 37) correctly answered the questions in the worksheet that asked which data set was the most accurate for the prediction among the five data sets consisting of different combinations of the variables. Figure 6 is an example of one student's answer. Students' responses showing that they understood the general idea of the AI algorithm were also observed by the teachers and two researchers in the three lessons. Excerpt 8 shows Tom's observation about the students' understanding.

> *R1: What do you think your students learned from this instructional package?*
>
> *Tom: Based on my students' responses, right? I think the learning that they had after the lesson, I say the majority, … they roughly know all AI is linked to models. It's like the order you need to feed data in and then it creates its own model and you can use that model to solve problems. … I think only a very small group of students will go on further and then they'll think about it. They will go on to think about other problems or deeper about AI, such as the model that they created also depends on the data that you fit.*

(Excerpt 8 from the Reflection, Tom)

We thought that the conceptual understanding of the AI algorithm was possible because of its well-visualized flow in the program, which can be seen in the middle column of Fig. 3. Tom also agreed with this idea, as shown in Excerpt 9.

> *R1: Do you think there is a benefit in using the Orange program in learning AI algorithms?*
>
> *Tom: I would say, after doing this Orange program, I do know this general process. Feeding the data into the AI, it analyzes it and it throws out some kind of model and then you see how the model is. … What benefits can I see about this program in AI? … I really don't know anything else about any other programs, but this program has served the purpose that I was hoping for. ….*


Data Recording

Data Set	High-High (%)	Low-Low (%)
mars_weather 1.csv	71.0%	73.1%
mars_weather 2.csv	70.9%	73.1%
mars_weather 3.csv	80.8%	83.4%
mars_weather 4.csv	80.9%	83.4%
mars_weather 5.csv	80.8%	83.4%

The percentages in the table above represent how accurate your model predicts the level of solar radiation on Mars.

Based on the data in the table above, which set of data would you use for your model?

4

Explain your reasons for choosing the above data set

It has the highest percentage and is most accurate

Hence, what weather data is/are useful for this model?

Humidity, pressure, temperature, wind direction

Fig. 6 A student's response to the questions about finding the most accurate model based on the percentages in the confusion matrix as a result of logistic regression

R1: So, do you mean that although you don't know the other programs, you know that this program provides some process visually to understand what you are doing?

Tom: Ah, yes, that would be the best way to say, yeah, it provides the visual part. Visual understanding of the flow of how the AI creates the model.

(Excerpt 9 from the Reflection, Tom)

What the students experienced in the lesson was actual data modeling that requires a rudimentary understanding of the AI algorithm. Although there were some black boxes in the processes, the teachers thought that the students mostly achieved the goal of the lesson. This is another point we can pay attention to in selecting an appropriate program or platform for AI involvement. For example, using block coding programs, which is a widespread phenomenon in STEM education, affords younger students opportunities to easily experience coding (Charters, 2003; Lane, 2021). Likewise, in selecting an AI platform for integrating AI into science classrooms, a critical consideration for educators should be its ease of bringing AI skills to younger students.

RQ2: What did the teachers identify as challenges in integrating AI into science lessons?

A lack of confidence in teaching AI to students: content knowledge and PCK

The biggest challenge of the lesson implementation perceived by the teachers was confidence in teaching AI content that was related to understanding (1) content knowledge and (2) pedagogical content knowledge. This result was a general challenge for teachers when they taught AI in classrooms in terms of the relationship between confidence in AI and how to teach it to students (Ayanwale et al., 2022). This was mainly because they had been trained as science teachers and may have had no background in AI unless they were personally interested in AI. The three teachers mentioned the challenge of teaching AI to their students during the reflection sessions. Chris shared his challenge in teaching AI (Excerpt 10).

Chris: I think the most difficult part of the lesson, as a teacher, was I might not have like a lot of confidence in explaining it to my students. If I have no background in AI and then suddenly I need to teach them what these different layers are doing, what the confusion matrix is. I also would have some trouble with that, so…

(Excerpt 10 from the Reflection, Chris)

It can be said the teachers' current concern was that they did not have sufficient knowledge and skills in AI. This challenge is indeed directly related to teachers' understanding of content knowledge, which is still a major part of teachers' professional knowledge (Carlson et al., 2019). As reported in recent studies of teachers' perceptions of AI (e.g., Chounta et al., 2022), teachers who majored in other disciplines tend not to have sufficient content knowledge of AI. Tom also faced this difficulty and tried to overcome it for the lesson (Excerpt 11).

Tom: I think the most challenging part was reading up about AI. I barely know enough about AI, so to be teaching it, I felt like I needed to know more in depth than what I was saying. In the process I read a few articles on the internet to summarize what AI is, what the different forms of AI are, and also the conversations with all of you over Zoom really deepened my understanding. The AISG website was also quite helpful. This was the most challenging part for me because I was not confident about my content knowledge of AI to teach it, and therefore most of my initial time was spent on developing my content knowledge rather than how to teach it.

(Excerpt 11 from the Reflection, Tom)

This suggests that teachers could make an effort to learn about AI. Teachers may also have pedagogical difficulties in teaching AI that go beyond understanding AI. Although the teachers intentionally taught the AI algorithm in a simpler manner in the lessons, which was illustrated in the first result, this could also cause teachers to have concerns about their pedagogical approach. Jennifer expressed her challenge in teaching the steps of using the Orange program (Excerpt 12).

Jennifer: It's back to the part where I mentioned how I chose to dedicate quite a big part of my lesson to going through the rationale of the different steps with the students ... To have clarity of the rationale of doing certain steps in the Orange program, I also led the students into why is it that you want to do certain steps ... I did it on the spot, I also didn't feel I did a very good job explaining it. Yeah, so I think that was the most difficult challenge.

(Excerpt 12 from the Reflection, Jennifer)

Jennifer was challenged to teach the rationale of each step in using the Orange program. After teaching them, however, she realized that she did not teach the steps well even though she spent significant time on the lesson. She might want to know efficient strategies for how to teach the simplified version of AI to the younger students. One of the common challenges when employing new approaches in classrooms is pedagogical challenges, such as how teachers step up and establish classroom environments in STEM education (Margot & Kettler, 2019). Likewise, integrating AI into an existing discipline such as science, as was the case in this study, may also lead teachers to question how to implement AI in their classrooms.

AI as a supplementary component of the current curriculum: temporal and audience issues

The teachers thought that teaching AI could be a supplementary component for science teachers, although not yet an essential one, that can be added to the existing curriculum. As mentioned above, science teachers are trained to teach science, so they may perceive AI as an additional layer on top of science even though there are some commonalities between AI and science. Considering AI a supplementary component would be relatively relevant to a discipline-focused orientation (Kim et al., 2021) in integrating AI into science lessons. Excerpt 13 shows how Tom perceived this integration.

Tom: I would say AI is a supplement. It's like an extra thing, adding on. Not as something that we use to teach other things. We used it to teach scientific concepts. Yeah, .. maybe we should teach the science concepts first when everything is OK and ready, then teach about AI. … I think that's more possible.

(Excerpt 13 from the Reflection, Tom)

Tom's statement also raised a temporal issue in implementing the integration of AI into science lessons. He seemed to have assumed that AI can be taught from the commonality of AI and science, in particular, creating a more accurate predictive model—which was shown in Excerpt 4 in the first result. Speaking in this context, the AI component can be introduced after learning the features of scientific models in a science subject to refine students' understanding of AI as a cutting-edge method of science. For example, climate modeling can be an exemplary topic for using AI as a scientific method as it is used in developing more accurate models to predict future weather, which requires a huge amount of historical data related to weather (e.g., Barnes et al., 2019). Naturally, Tom's perception might stem from a teacher's primary role: teaching science to achieve curriculum goals. When accomplishing the primary goal, teachers will then be able to teach AI by adding it on to the existing curriculum, as Tom mentioned. This teachers' prioritization of teaching science may cause employing the approach of AI integration with science lessons to be more challenging.

Another issue in integrating AI is targeting the audience. Since up to present there has been a dearth of empirical evidence on which grade and profile of students are most appropriate for teaching AI, targeting an audience can be a conundrum when integrating AI into science lessons. The teachers in this study felt that implementation of the AI lesson package would be appropriate in a science enrichment program for students who are interested in science (Excerpt 14).

> *Jennifer: I think at least my target audience was the bunch of people who I recruited for the lesson. The students were all part of the science enrichment program, so they were already the bunch of students already were very interested in science and did quite well in science. They have an inherent curiosity. Yeah, .. something, so I think it's a tall order. ... you can never cater to all student profiles, ... I'm not sure, but I would propose that maybe you just cater to, like, a science enrichment program. People who already are a little bit interested in science.*

(Excerpt 14 from the Reflection, Jennifer)

All three teachers agreed that at this point integrating AI into science is more suitable for students who are interested in science rather than all students. Their thoughts may have been more related to integrating advanced AI knowledge, such as logistic regression, which was used in the lesson package. However, realistically, it can still be challenging for teachers who are targeting all students, given teachers' difficulties in understanding both content knowledge and pedagogical content knowledge and their main focus on achieving curriculum goals. For a similar reason, a mathematics-focused AI subject in South Korea has been developed as an elective course for Grade 11 and 12 high school students (Ministry of Education, 2022). This curriculum was developed to foster students' mathematical competencies based on an understanding of the utilization of AI in mathematics. Likewise, if advanced knowledge of AI is integrated into science lessons, it can be suggested for students who are more interested in an enrichment program or an elective course. On the other hand, it's obvious that simpler AI concepts, which may not involve complex processes, should be further explored for integration into existing disciplines. This is particularly relevant as the breadth of AI literacy curricula (e.g., Touretzky et al., 2019) expands to reach a wider student audience, given their significance.

RQ3: What did the teachers recommend for the improvement of the AI-integrated science lesson package?

Improving teachers' AI literacy and implementing the AI-integrated lesson package for an enrichment program

The teachers' recommendations for improvement stemmed from their challenges with the AI lesson package implementations, focusing mainly on (1) teachers' AI literacy and (2) positioning of AI-integrated science lessons practically as an after-school program for students. The first suggestion was to provide comprehensive resources to support their understanding of AI content knowledge, because their biggest challenge was understanding what AI is and how to train an AI model and interpret the results of the trained model. Since science teachers are not generally trained to utilize and teach AI, they struggled with it. In general, teachers may need further AI literacy to teach AI to their students (Ayanwale et al., 2022). The following shows what Jennifer mentioned for the improvement of the package (Excerpt 15).

> *Jennifer: I'd like a kind of introduction to AI for teachers, not for students. So, I think teachers will appreciate greater clarity on what AI is. I seriously think that the main barrier to preventing buy-in from teachers is the lack of content mastery.*

(Excerpt 15 from the Reflection, Jennifer)

The second recommendation was employing this AI lesson package as an enrichment or after-school program. The teachers thought that this program would be more appropriate for students interested in science, based on their observations in the lesson implementations (Excerpt 16).

> *Jennifer: I would propose that maybe you just cater to like a science enrichment program. People who you know already are a little bit interested in science, and you know there's just like additional interest because I think if you want to push it out to like ...*
>
> *Chris: I think, as Jennifer mentioned, having this for maybe a selected group or of students who are in the science enrichment or like a science talent program. And I, I agree. I also think that this works best with that profile of students.*

(Excerpt 16 from the Reflection, Jennifer and Chris)

Although the teachers observed that their students for the most part achieved the goals of the lesson, they might feel the difficulty level would be high if this lesson was executed in general science classrooms. However, they perceived that this AI-integrated lesson could be applicable to Grade 7 students—Secondary 1 in Singapore—if they are interested in science (Excerpt 17).

R1: Which school grades, such as Secondary 1 to 4 or would be most appropriate for this instructional package? Why?

Chris: Appropriate for Secondary 1 students. However, if we want to focus more on the AI model architecture, it would only be possible in upper secondary [which is Grades 9 and 10] because of the prerequisite math knowledge.

(Excerpt 17 from the Reflection, Chris)

Since the AI lesson package did not require a precise logical understanding of logistic regression, Chris thought that it would be appropriate for Grade 7 students as a science enrichment program.

Discussion

Towards actualization of AI-integrated science lessons as an interdisciplinary integration

To expand the presence of AI-integrated science lessons in more schools, it is important to compile resources into accessible teaching materials and to bolster teachers' improvement of their capabilities and confidence. Drawing upon teachers' perspectives from this study and existing literature, we will discuss the organization of resources and teacher support in this section to actualize AI-integrated science lessons. First, organizing resources for an AI-integrated science curriculum may consider (1) identification of common themes between AI and science; (2) selection of a suitable program; and (3) data appropriate for the selected program. Resources, including lesson plans and teaching materials, could be co-designed around themes shared between AI and science. As demonstrated in this study, the development of more precise models through relevant data is a key concept shared between AI and science. Identifying a connection between AI and science could be the first avenue to deepen our understanding of how to integrate them using an interdisciplinary integration approach (Vasquez et al., 2013), which was applied in this study. The selection of a tool for teaching AI is another critical pedagogical consideration (see Table 1) in designing a curriculum, as indicated in the Theoretical Background section. The tool used in the lesson package was the Orange program, which offers a significant advantage in visualizing complex data modeling processes in ways understandable to both students and teachers. Since it may influence the range and complexity of AI content knowledge taught within the context of science, the tool should be carefully chosen considering the common theme and the tool's features (Ng et al., 2021). The data used for teaching AI should also be arranged in advance to coincide with the development of the AI-integrated curriculum. In this study, the data set was sourced from AI resources through a partnership with AISG. For science teachers, involving other educational institutions with AI experts may be more feasible than developing the data set themselves at the initial stage if the curriculum needs big data.

These three points can also align with the approaches of other AI-integrated science programs. For instance, classification inquiry in science and Google's Teachable Machine as an AI tool have a common theme—classification—and they have been arranged together in AI-integrated science curricula in several studies. Since Google's Teachable Machine is simple enough for younger students to grasp the basic concept of machine learning (Sanusi et al., 2023), this tool has been utilized in several AI-integrated science lessons. For instance, as cited in the literature, Shin and Shin (2021) used Google's Teachable Machine as an AI tool in teaching plant classification, integrating AI teaching into an online learning environment. In their study, they collected plant images in advance, using them to train and evaluate the machine. This approach reduced students' difficulties and ensured the quality of the data. With this in mind, when organizing resources for an AI-integrated science curriculum, teachers should intentionally consider these three points: common theme, program, and data, especially given the importance of tailoring the curriculum to their specific context (Dai et al., 2023; Lin & Van Brummelen, 2021).

Supporting teachers in actualizing AI-integrated science curricula is essential because they play a crucial role in implementation. However, many are not generally trained in teaching AI. Therefore, it can be beneficial to provide continuous PD programs for teachers to learn how to teach AI-integrated science curricula. Furthermore, collaborating with AI experts such as scientists or researchers for PD would be beneficial (Dai, 2023). According to the concerns-based adoption model (CBAM; Hall & Hord, 2013), which is a framework that indicates the level of teachers' engagement in implementing a new pedagogical approach (Ohlemann et al., 2023), teachers' main concerns typically progress through three broad stages over several years. Teachers begin by increasing their awareness of what the new approach is, its requirements, their potential roles, and the potential rewards and conflicts (self stage). They then move on to concerns about managing and implementing the new approach (task stage) and finally focus on the approach's outcomes, how to collaborate with colleagues, and how to refine the approach (impact stage). Given this model, continuous PD, encompassing both mastery of AI content and how to teach AI-integrated science curricula, should be offered to interested teachers over the years, bolstering their capabilities and confidence (Ayanwale et al., 2022).

In addition to continuous teacher PD, encouraging an environment that allows teachers to collaborate with other teachers and experts should also be considered. As indicated by the CBAM model (Hall & Hord, 2013), collaboration with colleagues is necessary to ensure successful outcomes from the implementation of the new approach. Regarding teachers' perceptions of STEM program implementations, research has shown that teachers believe collaborations increase the viability of these programs (Margot & Kettler, 2019). Similarly, AI-integrated science curricula can be more effectively executed through collaborative work among teachers. As found in this study, the three teacher participants also shared their experiences and challenges through reflection sessions. On the other hand, providing well-designed AI-integrated science programs to teachers is also important. Seeing the benefits of STEM programs for their students, which in turn influences teachers' beliefs about educational practices, helps motivate them to implement innovative programs in their classrooms (Van Haneghan et al., 2015). Likewise, in order for teachers to recognize the value of AI-integrated science curricula, the development of various high-quality programs is needed.

Engagement of epistemic practices of AI and science in AI-integrated science lessons

Teachers may utilize "black boxes" as a way of involving simplified reasoning in educational contexts, as illustrated in the Findings section, when they teach complex concepts (e.g., AI algorithms) at the beginning stage of AI-integrated science lessons. Since AI algorithms and other difficult concepts can be pedagogically simplified because of their complex nature, which would be a barrier to teaching, teachers may need to use black boxes in classrooms. However, this is fundamentally connected to the matter of epistemic practices—how we recognize the process of knowledge construction—which have become increasingly important in the information age, where knowledge production has been extensively enlarged in terms of credibility (Aradau & Huysmans, 2019). In this regard, although teachers purposefully use simplified reasoning at the initial stages, they may move on to unpacking the black boxes incrementally for students' better learning (Haskel-Ittah, 2023).

Teachers' use of unpacked black boxes in their lessons indeed relates to epistemic practices of AI and science. Although AI and science demand evidence-based high-quality outcomes involving inherent possibilities of error (Kim, 2022), they differ relatively in the transparency of the processes in school settings. Traditionally, scientific inquiry in classrooms has been done through the human agency of teachers and students, which has given more opportunities for epistemic practices. On the other hand, AI, and in particular, ML, has uncovered processes of big data modeling that lack transparency for teachers and students, which may cause trustworthiness issues. To overcome this transparency issue in ML, a key research area in AI, such as explainable machine-learning challenge (Rudin & Radin, 2019), is essential, as teachers should be able to manage the black box issue meticulously when integrating AI into science lessons. For example, during the implementation of this study's lesson package, it was necessary for the teachers to ask what kinds of data sets could make the model more accurate, allowing their students to unpack the black-boxed ideas associated with the relevant and quality data in the context. Indeed, in cases of appropriate educational contexts, such as a more knowledgeable group of students and aligned lesson objectives with features and data quality related to AI ethics, teachers can pose more in-depth questions related to reliability and validity. They can ask about the timing and methods of data collection, the magnitude of measurement errors, and so forth. This aspect was not the focus of this study, which is a limitation, suggesting the need for further research.

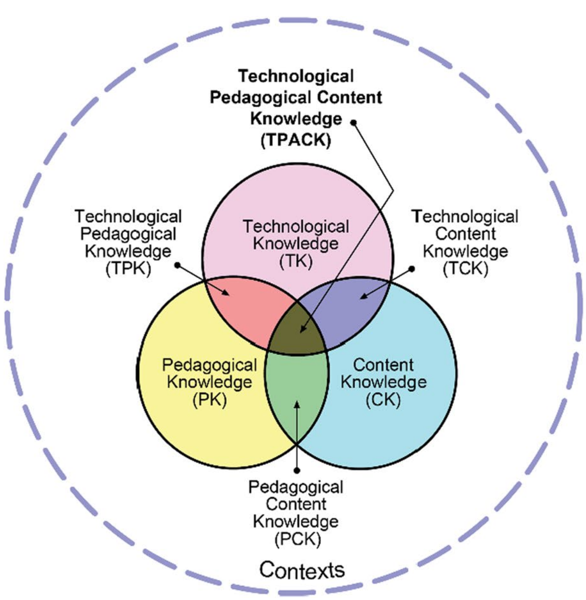
In this study, the teachers were able to appropriately use simplified reasoning with a program that shows a visualized flow of the modeling process. Consequently, the students achieved the goal of understanding a simplified idea of the ML algorithm and found the most appropriate data set to develop a more accurate model in the lesson, as shown in Fig. 4. This result shows that the students were able to come to a simplified understanding of the ML mechanism involving big data when supported by various resources. Likewise, even though starting with simplified reasoning can be done, teachers can transition to more in-depth discussion with their students for more meaningful learning experiences (Haskel-Ittah, 2023).

Conclusion and implications

This study investigated the teachers' experiences and their views in a case of AI integration into science lessons. We drew two implications through this study that may provide: (1) an empirical case in designing AI-integrated discipline-focused curricula and (2) a consideration for refining the AI-integrated TPACK framework. There has been increasing attention to teaching AI content in schools because the usage of AI will likely be a fundamental skill in the future along with existing literacies such as reading, writing, arithmetic, and digital skills (Ng et al., 2021). Although there has been an incremental number of empirical studies on teaching AI content using AI-focused orientations (e.g., Su et al., 2022), few studies have examined AI integration into existing disciplines, which is an area that needs to be actively explored so that AI can be used in school settings. In this regard, the case of this study could provide an empirical example of how to integrate AI into science-focused lessons involving Grade 7 students and their science teachers. As in this study's approach, exploring the relationship between AI and the existing discipline of science can be a starting point for integrating science and AI in designing curricular or lesson packages. In particular, as presented in the results of this study, it may be possible to teach the similarity between AI and science, which involves developing a more accurate model that enables the recognition of patterns from data at the beginning. Designing lessons can be followed up by situating AI and science as functioning in their complementary roles in the integration. It can then be helpful for educators in developing curricula to teach basic ideas on how AI works and why AI should be integrated into science as an existing discipline, encompassing a broader range of topics that may involve cutting-edge scientific methods involving a huge amount of data.

This exploratory study also provides consideration for refining the AI-integrated TPACK framework in consideration of the needs of an educational context where AI literacy has been increasingly emphasized in classrooms, where there is a need for interdisciplinary consideration that involves changes in each component for refining the AI-integrated TPACK model (Koehler & Mishra, 2009). This means that changes in the integration will happen not only to pedagogical and technological dimensions (i.e., PK, PK, and TPK), but also to content-related dimensions (i.e., CK, TCK, and TPACK) because AI enables the expansion of a range of existing disciplines in schools such as science and STEM, including their methodologies, as discussed. The current TPACK framework developments have had two different directions for involving AI technology: (1) as a supportive tool for teaching and learning and (2) as content to teach. Koehler and Mishra's (2009) TPACK mode, as shown in Fig. 7 (left), corresponds to teachers' capabilities in using AI technologies in ways such as identifying student performance and automated grading. On the other hand, related to AI literacy, Ng et al. (2021) suggested the AI literacy TPACK framework, as shown in Fig. 7 (right), which involves AI awareness, the use of AI ethics, and other key ideas of AI itself such as the five big ideas: perceptions, representation and reasoning, learning, natural interaction, and societal impact (Touretzky et al., 2019).

However, so far, there has been less attention paid to the discussion of how the content of existing disciplines would be changed. Since AI-integrated TPACK involves the interactive relationship among teaching strategies, subject matter, and AI technology, which is beyond the TPACK framework (Zhang, 2021), adding AI components into the TPACK framework may require an



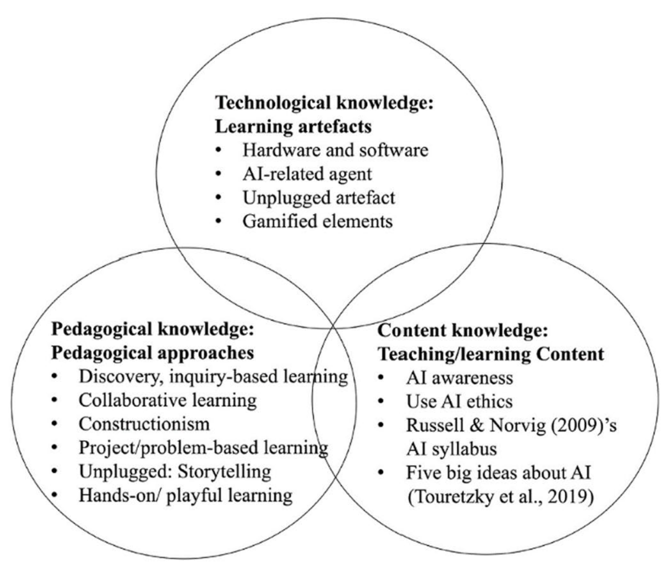


Fig. 7 The TPACK framework (on the left; Koehler & Mishra, 2009, p. 63) and AI literacy TPACK framework (one the right; Ng et al., 2021, p. 5)

understanding of how AI can be utilized as a tool for teaching, and AI as content to teach involves a further area of content knowledge, as shown in the findings of this study.

AI is not merely a technology being used for convenience: it also has enormous potential to change the world as part of the digital revolution (Makridakis, 2017). It essentially requires the need for educational innovations involving integrating AI technology to respond to the changes in society. In addressing the importance of AI literacy for learners, as it can be one of the fundamental skills in the future (Ng et al., 2021), this study explored a possible way to integrate AI into science lessons and investigated how teachers perceived the AI-integrated science lesson package in terms of practical considerations such as general science teachers' current understanding of AI, the science curriculum, and students' engagement. Starting with recognizing a need to integrate AI into existing disciplines in classrooms, which involves many challenges, this study aims to contribute to the further development of AI integration to develop students' AI literacy and learning an extended range of science subjects and STEM education using varied epistemic practices.

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Author contributions
JP (PI), TWT (Co-PI) and JSH (Collaborator) acquired funding and supervised the research team and were responsible for the conceptualization of this study. The instructional package for this study was developed by JP, TWT and AT, advised by SK (Collaborator). Data analysis was performed by JP, TWT and JC. The primary manuscript was mainly drafted by JP—theoretical background, methodology, findings, discussion and conclusion and implications, TWT—introduction and methodology, AT—methodology, and JC—theoretical background. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets generated and/or analyzed during the current study are not publicly available due to privacy protection of the participants but are available from the corresponding author on reasonable request. The materials for the AI-integrated science lesson package, including the video clip 1 (https://www.youtube.com/watch?v=OyznlW3GGaM), video clip 2 (https://www.youtube.com/watch?v=9fv-TatdW4g), and AI guide for students (https://drive.google.com/file/d/1VAr9S3KPEcteE7vlRXUBDG8TIEAIAU9d/view), are made available via the links.

Declarations

Ethics, consent and permissions
This study was approved by the Nanyang Technological University Institutional Review Board (No. IRB-2021-894). All participants provided informed consent. For those under 21, consent was obtained from their parents or guardians.

Competing interests
The authors declare that they have no competing interests.

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