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Using digital story writing as a pedagogy to develop AI literacy among primary students

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ABSTRACT

Artificial intelligence (AI) literacy is widely recognized as a new set of competencies that people use AI effectively and ethically in everyday life. In K-12 education, educators have started to employ different pedagogical strategies to foster students' AI literacy. Using digital story writing (DSW) in the classroom is an effective inquiry-based pedagogical approach to address literacy development by improving language and technological abilities across disciplines. This study recruited 82 primary students in Hong Kong to attend a three-month DSW journey to learn AI and completed a knowledge test at the end of the program. Among the students, 16 best-achieving students were further invited to participate in artefact-based interviews, and we further analysed their work to understand how they formulate AI understandings. It is found that the participating students were able to propose an authentic scenario, apply their new knowledge of AI and think up meaningful AI-driven solutions in their digital stories. Furthermore, we examined students' DSW process in terms of inquiry-based pedagogical cycle (orientation, conceptualization, investigation, conclusion, discussion) to demonstrate how they learn AI. Overall, DSW as an inquiry could effectively foster students' AI literacy in using and applying AI knowledge to solve real-life problems, far beyond merely knowing and understanding related concepts. We suggest that using DSW as a pedagogy has the potential to support students to scaffold students' AI understanding, particularly for young children.

1. Introduction

Artificial intelligence (AI) literacy is widely recognized as a new set of technological attitudes, abilities and competencies that people use AI effectively and ethically in everyday life (e.g., Burgsteiner et al., 2016; Kandlhofer et al., 2016; Long & Magerko, 2020). In K-12 education, despite the popularity of AI tools such as Siri and chatbots, students do not know about the concepts and technology behind, or are aware of potential ethical issues related to AI (Ghallab, 2019). When tools for teaching AI become more age-appropriate for K-12 students, they are no longer merely end users of AI technologies. Educators have begun to employ different pedagogical approaches to foster students' AI literacy. Therefore, a newly emerging term "AI literacy" has drawn the attention of researchers and educators to nurture the next generation to be digitally competent in AI skills and knowledge in order to be on a better footing for their future workplaces (Bawden, 2008).

As AI becomes more and more important in work settings and everyday life, researchers begin to define AI literacy based on the term 'literacy', which has been applied to define skill sets in varied disciplines (Long & Magerko, 2020; Ng et al. a, b). In the past, literacy was popularly understood as an ability to read and write (McBride, 2015). Nowadays, it has been extended to new arenas such as media, digital, information, computer and AI (Kong et al., 2021). Students who are equipped with these skills could use related technologies and computers in very advanced ways to learn new knowledge and skills with their counterparts (Bell, 2010; Griffin & Care, 2014; Larson & Miller, 2011). On top of learning these essential skills and knowledge, students need to learn how to use AI technologies judiciously, and discriminate between ethical and unethical practices (Robinson, 2020; Rodríguez-García et al., 2020). Since AI has become one of the important technological skills in the twenty-first century, educators need to combine AI and literacy to equip students with essential abilities and mindsets that they will live, learn and work in our digital world through AI-driven technologies. In other words, AI literacy should be taught at the K-12 levels (Steinbauer et al., 2021).

Researchers have already started to design pedagogy for students to learn about the working principles behind. They learn how to apply AI concepts and applications to solve problems in different contexts (e.g.,

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Ng & Chu, 2021a; Rodríguez-García et al., 2020). For example, Rodríguez-García et al. (2020) evaluated LearningML, a machine learning model builder, to encourage students to understand AI applications and how it can affect our lives, as well as knowing the ethical issues regarding AI technologies. Ng and Chu (2021) designed an informal learning experience for students to stylise and create an AI-driven stylised picture, and explore AI via gamification and online collaboration in a social networking site.

A considerable amount of research studies have identified digital story writing (DSW) is an effective inquiry-based pedagogical approach to enhance 21st century digital skills including information, media and technological literacy across disciplines such as STEAM education, computer science, and health studies (Frazel, 2010; Gubrium, 2009; Hill & Grinnell, 2014; Wu et al., 2020). As discussed, AI literacy is considered as one of the digital skills that people need to learn. We proposed that digital story creation could have a great potential to combine its pedagogy (e.g., inquiry-based learning) and related digital skills (e.g., information seeking, digital drawing, using AI-driven tools). This could enhance children's ability to acquire and apply AI knowledge, and create their stories to restructure their knowledge and demonstrate their understanding about AI (Julie et al., 2020; Wong et al., 2020). Through reading and writing stories, students can scaffold their AI understandings, and apply what they have learnt to construct stories and share views with their peers to co-construct knowledge when appreciating and critiquing other students' work. During the DSW process, students could use AI-driven tools such as proofreading software, translation tools and recommendation systems to facilitate their story creation. Therefore, this is meaningful to discuss the possibility of using DSW as a pedagogy to teach/learn AI literacy.

This article reports a case study investigating the instructional design of DSW in fostering AI literacy in a 3-month digital story writing learning program "AI, Robots, Love and Peace" among 82 primary students in Hong Kong. In the following sessions, we first provide a literature review of related studies on AI literacy and examine the potential of using digital story writing as a pedagogy to develop students' AI literacy. After proposing the research questions, the research methods and lesson design were described. The results are reported afterward, and the discussions of the major findings and implications for lesson design are presented. Conclusions and limitations of the study are outlined at the end of the article.

2. Theoretical framework

2.1. AI literacy

Artificial intelligence (AI) literacy is similar to classic literacy such as digital literacy and that it should emerge as a new literacy skill set that in response to this new era of intelligence. Although the definitions are varied, the common idea is that AI literacy is a new set of technological attitudes, abilities and competencies that people use AI effectively and ethically in everyday life. The term "AI literacy" was first proposed by Burgsteiner et al. (2016) and Kandlhofer et al. (2016) that it is an ability to understand the basic knowledge and concepts behind these AI-driven technologies. In addition to knowing and using AI ethically, AI literacy serves as a set of competencies that enable individuals to critically evaluate AI technologies, communicate and collaborate effectively with AI (Long & Magerko, 2020). Further, Ng et al. (2021a, b) added AI to every learners' twenty-first century technological literacy in work settings and everyday life, and proposed AI to become a fundamental skill for everyone, not just for computer scientists. Inspired by Bloom Taxonomy, AI literacy is conceptualized as the cognitive levels across the spectra of AI learning inquiry with four perspectives, namely, know and understand, use and apply, create and evaluate, as well as ethical issues (Ng et al., 2021a, b).

Thirty years ago, computer applications gained popularity across industries. This drives the need for users to become digitally competent in using computer systems related to their specific task or job. As such, the term 'digital literacy' emerged to assess basic computer-related concepts and skills. The importance of digital literacy increases as more people depend on the use of computer technologies to develop new social and economic opportunities (Leahy & Dolan, 2010). Similarly, in succession to digital advancement, AI technologies started to arise and imitate human intelligence in machines for computers to learn, reason and perceive. AI started to gain its importance in scientific and engineering research, and academic environments, and had become ubiquitous in our daily lives in the 2010s. Based on Bloom Taxonomy, Ng et al. (2021a, b) framed a theoretical model to conceptualise how AI literacy is described in following four cognitive standards.

Know and understand AI. The first most fundamental definition of AI literacy has focused on basic AI concepts, skills, knowledge and attitudes that require no prior knowledge. Instead of merely being the end users of AI applications, students should understand its technologies and working principles, especially when AI learning tools (e.g., teachable machines, robotics) become more age-appropriate for students to implement their machine learning models. In K-12 education, researchers designed learning curriculums and hands-on activities that foster AI literacy that focuses on how students gain AI concepts (e.g., Druga et al., 2019; Ng & Chu, 2021a). For example, children could learn AI via playing, looking and feeling with smart toys and AI agents. Robotics is also a common tool to facilitate children to recognise different objects and people. When they saw and realized that the robot could pick up a cube it had just recognized, they became amazed (Druga et al., 2019). Moreover, some recent AI-driven technologies such as simulation (e.g., Teachable Machine) and drawing tools (e.g., image stylizer) could bring children engaging and interactive experiences to explore AI (Ng & Chu, 2021a).

Use and apply AI. After knowing the AI concepts, applying AI concepts and applications in different contexts is the second cognitive level that students could reach (e.g., Druga et al., 2019; Lee et al., 2021). When using AI, human-centered considerations and focusing on using AI concepts and application ethically would also be important issues for the societal good. On top of using AI ethically, some researchers borrowed the ideas of computational thinking to interplay AI literacy and AI thinking (see Table 3). AI thinking refers to the construction of logic and algorithms in order to support students' understanding of how to use knowledge bases for problem-solving, processing semantics and handling unstructured data (Vazhayil et al., 2019). For example, How and Hung (2019) leveraged AI thinking through conducting data

Table 1
Characteristics of the participants.

No.	Name (fictitious)	Gender	Level of study	Story name
Junior form students (Primary 1–3)				
J1	Hung	Female	Primary 1	The Adventure of Princess Wawa in Kanga Land
J2	Yi	Female	Primary 3	Romy and Me
J3	Max	Female	Primary 3	Kelvin, the New Security Guard
J4	Tse	Female	Primary 1	The Day after 2099
J5	Kong	Female	Primary 2	The Robot and the Kungfu Girl
J6	Elva	Female	Primary 3	The Robot Princess
Senior form students (Primary 4–6)				
S1	Leung	Female	Primary 4	Love and Peace - Lily Saves the Animals
S2	Hai	Female	Primary 6	The Restaurant
S3	Trinity	Female	Primary 6	A Trip to the Future: AI Takes Over the World?
S4	Hin	Male	Primary 5	The Future of the Earth
S5	Ho	Female	Primary 4	Blubber - The Sea Robot
S6	Chung	Male	Primary 5	Smartbot's Amazing Adventures
S7	Pak	Male	Primary 5	The Peaceful Confrontation
S8	Sammy	Female	Primary 5	Health Alliance
S9	Athena	Female	Primary 5	You in the Sea, I Only Have Feelings for You
S10	Mok	Female	Primary 4	The Queen's New Face Mask

Table 2
Coding framework of AI literacy.

AI literacy	Definitions	Sample sentence	Sample artefact
1.Know & understand AI	Know the basic functions of AI and how to use AI applications.	*Smartbot is the robot that Hayden invented. He is an **artificially intelligent** robot. He has the reactive functionality of **sensing, scanning capacity** in order to **identify people's emotions, actions and different sounds.** The best thing is that he can transform into any machine.*	Smartbot's Amazing Adventures
2.Use AI	Applying AI knowledge, concepts and applications in different scenarios.	*"What should I do?" Lily wondered. Lily **called Siri** and **Siri said**, "Use some bandages. Stop the bleeding!"*	Love and peace—Lily saves the animals
3.AI ethics	Human-centered considerations (e.g., fairness, accountability, transparency, ethics, safety).	*AI found the "true wisdom" in this world. **Nothing is more important than love and peace (be fair, inclusive and harmless).** Highest wisdom is **not conquering but to love one another.***	The Day After 2099
4. Evaluate & create AI	Higher-order thinking skills (e.g., evaluate, appraise, predict, design) with AI applications.	*At school, I also **construct robots with sensors** … and I have learnt how to use AI arts to combine the painting styles and **create a new work**.*	Kelvin, The New Security Guard

Table 3
Interplay between AI and Brennan and Resnick's (2012) computational thinking.

Elements	Descriptions	Examples
AI concepts	Technical and conceptual understanding of the basic AI concepts.	Classification, prediction and generation.
AI practices	The techniques and strategies used when applying AI.	Training, validation and testing. Remixing or reusing code.
AI perspectives	Attitudes and dispositions adopted while solving problems.	Collaborating to solve problems, understanding of technology as a problem-solving tool.

analytics with computing, and interpreted new findings from the machine-learned discovery of hidden patterns in data. All these abilities indicated that students could apply their AI concepts to express solutions in different contexts.

Evaluate and create AI. AI augments human intelligence with digital automation and alludes to AI literacy to engage learners in higher-order thinking activities. Other than knowing and using AI with concepts and practices, studies had extended AI literacy to other competencies that enabled students to critically evaluate AI technologies, communicate and collaborate effectively with AI, and create AI-driven artefacts (e.g., Long & Magerko, 2020). For example, Han et al. (2018) enhanced students' scientific and technological knowledge which then was applied in scientific research-based learning to solve practical problems. Long et al. (2019) engaged citizens in co-creating and experiencing AI-driven installations in public areas and museums to develop their AI literacy and experiences.

AI ethics. As AI plays an important role in day-to-day decision making, misused or poorly designed AI could cause irreparable harm to humans and the society (Jobin et al., 2019). AI-concerned scientists and engineers like Elon Musk expound on the horrors that future AI technologies may wreak on humanity in decades to come (Johnson, 2019). Gong et al. (2020) found that students pay little attention to ethical concerns such as bias in AI and legal responsibility (8%), and intellectual property (9%). It could be hazardous to use and design AI technologies without safety and ethics guidelines. As such, it has been increasingly important in recent years to include human-centered and ethical considerations to educate students to become socially responsible when using and designing these applications (Ahmad et al., 2020). Previous research that incorporated ethical considerations such as algorithmic bias and ethical design of recommender systems into AI and Ethics curricula found that students were able to engage with these concepts (Lee et al., 2021). Therefore, educators should not only focus on developing students' AI abilities and interests, but also help students to realize the societal impact and ethical concerns.

2.2. Using DSW for AI literacy development

Catalyzed by the worldwide STEM and maker movement, researchers raised a new focus on the impact of making to provide new opportunities for learners to engage in constructionist practices with digital technologies (Hughes et al., 2017; Laurillard et al., 2013). Constructionist practices stress the importance of digital tools, media, and learning context (AI) and encourage learners to build new knowledge and understand the world around them through making sense of their experience and constructing meaningful artefacts (Ackermann, 2001; Papert, 1980). Many of them emphasize the hands-on making through using technologically enhanced artefacts such as simulators, mobile apps and robotics (e.g., Ng et al., 2021; Ng & Chu, 2021b) but many tied digital story writing (DSW) to constructionist theory (e.g., Green, 2013; Hafner & Miller, 2011).

DSW is a combination of pedagogy and technology to foster student's ability and acquire different subject knowledge. It facilitates students to learn new cognitive concepts and combine different semiotic systems (Smyrnaiou et al., 2017), and combine narrated audio texts, images, videos and other multimedia elements to create media artefacts (Boase, 2008). It is a powerful cognitive development tool to combine language, visual, and digital representation could enrich how students used images, sound, and movie editing techniques to express causality and development from one scene to another. During DSW experience, students have the learning opportunity to apply their prior knowledge, research, reflect from their daily life experience (Boase, 2008), explain and construct a finalised story.

In the context of AI learning, DSW has changed the learning opportunities for AI literacy development. First, it broadens opportunities for students to use academic language proficiency such as reading and writing to explore new knowledge (Barber, 2016; Uccelli et al., 2015). It renders to learn abstract AI concepts and ideas accessible to younger children. In constructing a story, students firstly have to observe, know and understand AI knowledge. Then, they organize, classify, and analyze the main elements of scientific notions to synthesize their cognitive frames. Wong et al. (2020) suggested that storytelling could encourage students to explore how to interact with sensors, discuss why AI has an impact on everyday living, recognise different AI applications and why AI ethics such as safety may be an issue in our society. Students could gather information and read to construct knowledge and connect with their everyday experiences such as using sensors and societal impacts about AI (Yuksel et al., 2011).

Second, DSW provides a strong foundation in multimodal literacies by shifting verbal to multimedia modes in which students apply their prior knowledge and express it in media formats (e.g., Eisenlauer & Karatza, 2020; Yang, 2012). DSW as a pedagogy combines different semiotic resources, such as speech, text, gestures, graphics, music and video presentations for students to "talk about the topic, to communicate about it, to tell and write a story about it" (Dougherty, 2012, p. 13).

Table 4
Five phases in inquiry-based learning.

Phases	Inquiry-based learning	Using AI-driven chatbot as an example
Orientation	● Students get ideas about the topic to be investigated and introduce the problems to be solved. ● They then do observations and research that guide them to explore a specific phenomenon.	● Generate a writing topic about AI-driven chatbot design. ● Introduce problems to be solved in the story (e.g., how chatbots for restaurants can facilitate waiters' work). ● Make observations from everyday life and research from the Internet and books (e.g., chatbots can help waiters greet customers, detect customer intentions and confirm orders).
Conceptualization	● Questioning: Students generate questions, search for information on the web and analyze it. ● Hypothesis generation: They then make hypotheses and brainstorm solutions and ideas for their project.	● Ask questions (e.g., what are chatbots used for in daily life?). ● Generate hypotheses and brainstorm solutions for their stories (e.g., generate a working flow and characteristics of a chatbot in the story).
Investigation	● Exploration: Students carry out their plans or experimental design, investigate, observe, collect evidence to address the proposed questions. ● Data interpretation: They can also analyze and represent evidence, evaluate, generate synthesis, identify patterns, make inferences and make sense of online information.	● Carry out writing plans and explore the issue (e.g., how the robots' characteristics match the story lines and scenes to solve the proposed problem). ● Analyze the existing chatbot designs that are used in restaurants, and write the stories that make sense according to students' information findings and evidence.
Conclusion	● Students construct reasonings with models, solve problems, draw conclusions and offer solutions via reports, and make judgements based on the inferences.	● Create and construct their stories to offer solutions to solve the problems suggested in the story (e.g., the chatbot becomes the waiter's companion to help him survive a crisis in his restaurant).
Discussion	● Communication: Students discuss and share their inquiry, justify explanations, generate arguments and new understandings. ● Reflection: They can also reflect on themselves and evaluate their performance.	● Discuss and share their inquiry about the story. Justify explanations and misconceptions and generate new understandings based on the story. ● Reflect on themselves and evaluate their performance (e.g., are there any ethical or privacy concerns to use the chatbot?)

Students could use digital story creation tools such as web-based creation platforms, blogs and wikis to develop significant information technology skills, information literacy and language abilities (e.g., Woo et al., 2013). Students could apply what they have learnt and reinterpret AI concepts through digital story creation using these semiotic resources and tools. They write texts that are enriched with related pictures or sound in accordance with the AI context and meaning. This procedure is improved when students are influenced by their parental and teachers' support, students' collaboration and social interaction. As such, their stories could transfer their beliefs, values, and own perception of the AI and everyday world.

Today's society demands multidisciplinary and digital skills which could strengthen students' capabilities to apply their knowledge for personal and social empowerment for communication and creation via media and information channels. As discussed in the above section, DSW as a pedagogy could combine content knowledge (AI context) and multimodal technology (text, audio, image, gestures, videos) which scaffold students' AI understanding and encourage them to explore this new field of knowledge and create their own stories using digital skills via video making and graphics drawing. Therefore, this article proposes to use 21st century digital literacy as the basis for its sound implementation in the context of AI literacy. The identified digital skills are technical, information, communication, collaboration, creativity, critical thinking and problem-solving (Van Laar et al., 2017). Using DSW could demonstrate its potential to be one of the important information, media and technology skills in 21st century learning (Long & Magerko, 2020; Wong et al., 2020). Throughout the DSW creation process, students need to obtain the AI-related skills that they need to live, learn, and work in a society to facilitate them to communicate and access new information through AI and digital technologies.

2.3. Inquiry-based learning and DSW

Prior research has shown the role of inquiry in reading and writing as a way to acquire new knowledge and a method of restructuring their knowledge (Chu, Reynolds, Tavares, Notari, & Lee, 2021; McGinley & Tierney, 1988). For example, Kaeophanuek, Na-Songkhla, and Nilsook (2019) categorised the critical inquiry learning process to propose a model to enhance students' digital literacy such as information skills, socio-emotional skills and cognitive skills through DSW based on 12 students' work. Five critical inquiry methods were identified. First, this pedagogy could stimulate students' thinking, and encourage them to raise critical questions to undertake research and obtain knowledge. Second, students can explore information from multiple learning sources and illustrate problems for a variety of solutions from learners' experiences and learning processes. After gathering information, students need to further analyze the resources they found and expand their knowledge through discussion and collaboration with others. This could deepen their understanding and expand the scope of their knowledge. Finally, students could reflect on themselves and sharpen their learning process.

Other studies also suggested the roles of reading and writing to scaffold students' understanding in a particular discipline via inquiry-based learning. For example, Harrison and Parks (2017) identified a collaboration between STEM learning and inquiry-based writing to help students create meaningful STEM learning experiences via stimulating intersection of cognition and creativity, sharpening their critical thinking and problem-solving skills. Another study conducted by Ashbrook (2013) believed that reading could extend student STEM learning about making observations, investigating engineering design problems and demonstrating with digital artefacts. Although these studies have mentioned a list of abilities that students could gain through inquiry-based reading and writing, few generalised the most common core phases of inquiry-based learning via reading and writing to reflect the different implementations.

A review was conducted by Pedaste et al. (2015) in response to this research gap and developed a five-phase inquiry-based learning model based on learners' perspectives in 32 studies. This model summarises the core features of the inquiry-based learning process that combines the strengths of the existing studies. The review categorised a list of 109 learning behaviours (e.g., observation, finding a topic, searching for information, synthesizing) to formulate the five phases including orientation, conceptualization, investigation, conclusion and discussion. Among these studies, two studies focused on students' development of computer and technological literacy in the context of science learning. Zhang and Quintana (2012) applied an online inquiry approach to facilitate students to generate scientific questions, search for

information on the web, evaluate and make sense of online information, and integrate different pieces of information to formulate solutions to solve problems. Furthermore, Wecker et al. (2007) designed an inquiry-based environment for 37 students in a secondary school working in pairs on the project 'How far does light go?' to enhance their technological literacy skills (procedural computer-related knowledge, self-confidence in using the computer, and familiarity with computers). Since AI has become one of the important technological skills in the twenty-first century, we can see the potential of using this model to examine students' development of AI literacy via the DSW processes. Table 4 describes how inquiry-based learning is applied in digital story reading and writing processes using AI-driven chatbot design as an example.

2.4. Research gap

As AI becomes more and more important, researchers began to define AI literacy based on the term 'literacy' which has been applied to define skill sets in varied disciplines (Long & Magerko, 2020). However, few studies have provided comprehensive explanations on how to conceptualise AI literacy. Second, although educators have rich experience in incorporating DSW in encouraging students across disciplines, definitive evidence that using DSW in fostering students' AI literacy in K-12 education has yet to be established. It has yet to be examined whether DSW could effectively foster students' AI abilities and interests, and how students perceive such digital story writing experience. With the great potential of using DSW, this study aims to address these gaps, by analysing student's interviews and digital artefacts (i.e., digital stories) that ultimately provide more evidence to conceptualise the term 'AI literacy'.

Therefore, the focus of this article is to address how DSW fosters AI literacy; to this end, we will address the following research questions:

Q1. How does digital story writing foster upper primary students' AI literacy?

Q2. What inquiry-based learning processes did students demonstrate through digital story creation to learn AI?

3. Methodology

A mixed research method was used to collect self-reported data through semi-structured interviews and survey responses which aimed at triangulating data from both students and parents (Creswell et al., 2011, pp. 541–545). We recruited over 82 primary school students in Hong Kong to participate in 7-day workshops to learn digital story creations and AI knowledge in three months. The learning program entailed teaching the student participants to create stories in Storyjumper (a platform that encourages students to create, narrate, and publish their digital stories online). While quantitative data was collected using post-test and the qualitative data was collected using interviews and students' writing artefacts. To evaluate the acquisition of AI knowledge from their DSW experience, all the students were given a post-test within one week after the intervention. Teachers were invited as judges to assess and comment on students' work according to the rubrics, and eventually 16 best authors and their parents were further invited to participate in follow-up artefact-based interviews to evaluate their learning processes throughout the DSW experience. The reason for the 16 students with the best performance in the competition to be selected is that we would like to investigate the positive implementation that DSW as a pedagogy could bring to students in AI literacy education. Future studies could explore the challenges that lower-achieving students met throughout the DSW learning. Table 1 demonstrates the demographic information of the interviewees.

3.1. Lesson design

Over the three months, students were asked to create a digital story under the theme of AI in a DSW competition. The first two months covered seven workshops for students to learn how to create digital stories including writing skills and technological skills, as well as equipping students with basic knowledge of AI. In the third month, students started to create their stories and were encouraged to use any database or search engine to search for extra AI knowledge to enrich their understanding, thus polishing their stories. The major focus of the intervention is to adopt the DSW approach to learn AI. As such, we focused on describing AI-related learning tasks instead of language learning tasks. The learning design and activities are described in Table 5.

In the first month, four lessons were conducted and the writing theme "AI, Robots, Love and Peace" and rubrics for assessing students' work were introduced at the beginning. Throughout the workshop, we equipped students with reading and writing skills to use AI as a learning context, as well as AI knowledge provided students with several AI-related learning tasks. First, AI ocean activity in code.org engages students in knowing machine learning, training data, and bias, while exploring ethical issues and how AI can be used to address world problems. Second, students learn how to use an AI-driven stylizer which combines the image contents (e.g., object structure, specific layout) and image style (e.g., colour, texture, patterns in strokes, style of painting technique). They can generate fascinating painting work that is difficult to produce manually. The output matches the content data and style data of the selected images and these data are extracted from images using a convolutional neural network. For example, students could generate an image that has the content image of Mona Lisa but it was painted by Van Gogh's style of his artwork 'starry night'. Third, Quickdraw is an online game developed by Google that challenges players to draw pictures of an object and then uses a neural network to guess what the drawings represent. The game builds its machine learning model to learn from each drawing so as to enhance its ability to guess correctly in the future. Students could learn the working principles behind the game. After the three tasks, students completed a gamified Kahoot! game to sum up the AI-related terms that they have learnt throughout the activities.

In the second month, we discussed the uses of AI-driven robots and

Table 5
Lesson design.

Months	Lessons	Learning activities
1	1–4	● Learn how to read and write a creative story to promote the theme "AI, Robots, Love & Peace" in a competition. ● How to create a digital story? What is AI? How to write a story about this? ● Complete AI-related learning tasks (Code.org, Quickdraw and image stylzer) to understand the working principles of machine learnding. ● Complete a gamified Kahoot! game to learn the terms of neural network, data bias, Python language, chatbots, machine learning, etc.
2	5–7	● Discuss the uses of AI-driven automated robots: What are their present and future roles in our society? How to write fiction or non-fiction about it? ● Learn to make inquiry and how to critique students' work. ● Discuss the parents' role in their children's story creation. ● Use AI-driven translations to translate students' stories from their native language into English. ● Generate drawings inspired by some constitute famous artworks. Students are asked to attempt to convert their drawing into the art inspiration's style. Students witness examples of AI doing a style transfer.
3	Presentation day	● Students make their story in the third month. They are invited to present their story and appreciate others' work. Teachers will access and comment on students' digital stories.

their future roles in our society. Second, to create a digital story, students learnt how to use AI-driven translation software to translate their stories from their native language into English, and AI-driven image stylizers to create some illustrations in their digital story books. These tasks are important for students to learn the AI applications through designing multimedia elements in their digital stories. At the end of the third month, all participating students were invited to present their stories and the teachers will assess them according to the rubrics. Students could appreciate and critique each other's work.

3.2. Student and parent interviews

The students' interviews aimed to explore their learning perceptions when participating in the digital story creation and AI learning activities, and examine how it could foster students' AI literacy development. This study recruited 82 primary students in Hong Kong to attend a three-month DSW journey to learn AI and completed a knowledge test at the end of the program. Among the students, 16 best-achieving students were further invited to participate in artefact-based interviews, and we further analysed their work to understand how they formulate AI understandings. All of the 16 students had actively participated in all learning activities. Among the 16 best-achieving students, 13 of them are female, which indicates that DSW learning stimulates female learners to perform better than boys to learn AI.

During the interview, we first validated students' work to make sure that their digital stories are solely created by the students, without having someone substitute them to write their books. For example, students were asked how their thinking, beliefs and conceptions about the topic that has been built. Then, we examined how students design their stories using AI concepts with learning artefacts (e.g., digital stories, schools' AI-related work and projects, classwork) and which cognition levels of AI understanding they achieved. The question protocol for parents and students is described as Appendix 1. After that, we transcribed and coded their conversations and recorded students' artefacts for further analysis. A consent form was sent to the parents and their students before conducting the interview. Each interview was administered for about 30–45 min in the relevant language.

4. Results and discussion

4.1. Q1. How does digital story writing foster upper primary students' AI literacy?

Students found the DSW experience to be positive and beneficial. A post-test was administered to assess students' basic understanding of AI knowledge using a 5-point Likert scale. Over 53% of the participants (N = 82) received an above-average performance (M = 3.18; SD = 0.95). After that, interviews were conducted to collect students' learning experience on AI and digital story writing process via Zoom or phone. Students' digital stories and STEM-related artefacts throughout the learning processes were collected to examine how students foster their AI literacy throughout the DSW process. The same interview protocol was used in interviews and would facilitate researchers to categorise students' work and feedback in the four main aspects of AI literacy (see Table 2). Their recordings were then transcribed and coded. Inductive thematic analysis was then used and grouped patterns of shared meanings into four themes: know and understand AI, use and apply AI, evaluate and create AI, and AI ethics.

Know & understand AI concerns how students know the fundamental AI concepts and how to use AI applications in everyday life ethically. In this stage, students need to build awareness through playful and hands-on experience to explore AI topics. They experiment with the theory behind certain AI topics using digital technologies including web-based machine learning simulation and tools (e.g., Quickdraw, Teachable Machine), and hands-on making experience (e.g., robotics making, game design). From the interview, all of the 16 participants claimed they have demonstrated the meanings of AI functions and use AI-driven applications (e.g., translation, Siri) in their DSW journey. They gave examples of how these AI-driven applications imitate humans (e.g. talking, walking, object/voice recognition, sports and paintings). Follow-up questions were asked to ask students to further explain the meanings of AI.

For example, A student named Leung created a digital story called *Love and peace—Lily saves the animals.* In her story, Lily, a girl who loves hunting games, saves the animals in the games with the help of an AI-driven robot with Siri functions. The robot can communicate with people and offer useful tips about how to take care of injured animals, and recognise weapons and destroy them. Leung stated, *"Before the workshops, I didn't know what AI was. Now I know that AI is about automation, object/voice recognition using data. Through digital story creation, my AI concept can be deepened. Although I could not fully understand all AI concepts during the workshops, I got some ideas (*e.g., *robots, automation and object recognition)."* Her mum agreed that Leung had benefited from the DSW in terms of AI learning and story creation. *"Based on my observation, she makes up her own story and she believes that AI robots can identify injured animals and save them … In the workshop, she learnt how AI recognizes objects, and then she put this concept in her story."* Moreover, more advanced AI can learn to recognise objects and help us solve problems such as the presentation design. "*AI learns from data, upgrades its algorithms and makes models more accurate!*"

Use and apply AI concerns how students apply AI knowledge, concepts and applications in different scenarios. After experimenting and familiarizing with the theory behind certain AI topics, students were encouraged to apply the AI knowledge that students have learnt and work independently on solving specific problems. This comprises theoretical and hands-on elements based on collaborative project-based and problem-solving approaches. When constructing digital stories, we observed that all students could explain how their main characters in their stories apply AI abilities to solve specific problems. For example, Sammy found that elderly people had many inconveniences in daily life so she designed AI-driven robots with sound recognition to facilitate the elderly to do housework. The robots also helped the eldely to recognise the expired food at home by checking the expiry day automatically. Although students may not need to make a real robot and solve specific problems, students could learn how to incorporate theories behind and verbally explain how their AI robots work to deal with these scenarios.

A student Hai shared her story about an AI-driven waiter to show how students apply AI in her robot chef: "*The robots can recommend some tasty and healthy recipes according to people's willingness. It suggests to people which food he/she could choose in a restaurant. It can also help people cook and save human power.*" Another student Ho created a robot that can use computer vision and machine learning to design an intelligent robot that can analyze and sort items for recycling: "*AI can get trained to recognise and separate recyclables. Then, the non-recyclable items would be collected to the burning furnace.*" Another student Max developed an AI-driven security guard that has a list of advantages compared with a human safeguard. For example, the security robot is not going to be sick, need vacation time, and work consistently on what they are programmed to do, report back accurately on what they see and react to an emergency quickly. "*Kelvin (the AI-driven security guard) has functions such as facial recognition and it can know who are the residents of the building. It knows how to recognise and put out fires according to temperature/colour in an emergency. It can help firefighters to ensure residents' safety!*" These conversations could demonstrate how students incorporate AI concepts into their stories.

In addition to using and applying AI concepts in different scenarios, students learn how to use AI-driven tools to conduct specific tasks. During the workshop, instructors introduced students to different AI tools to generate stunning visuals, profound poetry and transcendent music. Students could use AI tools to create artwork, compositions and music pieces that are aesthetically pleasing without mastering the painting, writing and composing techniques. In our workshop, creative

machine learning techniques and AI-driven tools were demonstrated to encourage students to create artwork. The nature of art and the role of human creativity in the future start to become reachable. Students explore tools and techniques such as neural networks across various forms of media such as text, images and music to enhance students' creative and imaginative capabilities which facilitate students to enrich the multimedia elements in their digital story books. For example, students chose a photo or artwork (Houses), and chose a painting style (Van Gogh style) to design a new artwork (houses in Van Gogh style) (see Fig. 1). Students can also change some settings of the finalised work such as gradients, brush and colour adjustment. After discussing the "drawing" techniques, it is important to highlight ethical issues about generative AI including the ownership of artwork and generation of fake media throughout the workshop. In other words, we encourage students to use and apply AI tools ethically.

Evaluate & create AI is defined as the higher-order thinking skills (e.g., evaluate, appraise, predict, design) with AI applications. Although people may argue that using AI tools to express ideas and solve problems should reach the cognitive levels of evaluating and creating artefacts (e.g., artwork, music pieces), we classify this as the "use and apply AI" level. This is because this type of work creation may not require students to adopt their AI knowledge and create new AI-driven artefacts. As such, using AI tools to create a work does not necessarily mean that students could create AI-driven artefacts.

While AI has proved superior at complex calculations and predictions, creativity seems to be the domain which machines can't take over. To reach the level of evaluating and creating AI, students need to achieve the former two levels (i.e., know and understand, use and apply AI). They could transform their AI knowledge and apply related technologies into different scenarios and design solutions to solve specific problems. In this problem-solving process, students would need to evaluate, compare and consider different strategies and algorithms to implement their ideas. At the end, we interviewed how DSW experience facilitates students to create their AI artefacts in their STEM learning. It is found that although all students could successfully create their AI-driven main characters in different scenarios to solve problems designed in their fictional stories, it is difficult for researchers to see how students could explain different strategies and algorithms to implement their robots in their stories.

Out of 16 students, there are only two students who could successfully demonstrate how they design their algorithm in their school projects and marginally reach the "evaluate and create" level. For example, Leung screen-captured her Scratch game and showed us how to train a machine learning model and program a chick on the screen that could respond to us using a camera with the use of AI techniques. Another student Lily trained the computer to recognise two objects (i.e., fingers and a lego brick) (see Fig. 2). *"When you want to train the machine learning model, you need to collect data first and capture 30 pictures of two things. Say I use a finger and lego brick. After taking 30 pictures of them, we can set the if … then … statement That is, if the chick recognizes I show a finger, it jumps."* This indicates that students could reflect their AI understandings in their schools and transfer their knowledge to solve some specific problems in their story books. The rest of 14 students believed that they could not reach this cognitive level because their school teachers have not delivered them any AI knowledge in schools. They claimed that our learning program offered them the first experience in learning AI to create a digital book. For example, Trinity said she has learnt how to write programs to control motors and hardware, but she could not show us any AI-related artefacts that have been created before at school. This way, we could not count her to reach the cognitive level of evaluating and creating AI.

AI ethics are moral principles that involve different human-centered considerations (e.g., fairness, accountability, transparency, ethics). When AI-driven technologies are transforming the world, AI ethics becomes important to bring up responsible citizens to use and apply AI technologies ethically. Researchers and practitioners started to propose AI ethical principles to guide the different industries and educate responsible citizens who could compete in using AI in a reliable, trustworthy and fair way (e.g., Hagendorff, 2020; Jobin et al., 2019).

In the workshop, an instructor introduced students to some online AI experiments such as image stylizer and Quickdraw. Quickdraw is an online game developed by Google that challenges players to draw a picture of an object using a neural network to guess what their drawings represent. Through the hands-on simulation of AI applications, students could recognise the importance of data bias and it is important to avoid unjust impacts on people, particularly those related to sensitive characteristics such as race, ethnicity and gender. The discussion shows how AI works in Quickdraw, and its related ethical concerns and sources of bias. For example, an instructor suggested a reason that causes ethical issues, and said, "*Designing fair and unbiased algorithms is one of the challenging problems nowadays in our technological world. For example, in the Quickdraw game, people perceive shoes in a different way. Some draw high heels; some draw sandals; some draw business shoes. The app will collect over millions of people's drawings to train the model that could recognise users' doodles. If those datasets underrepresented or overrepresent certain groups, it's not a fair model. A software engineer pointed out that the image recognition algorithms in Google Photos were classifying his black friends as 'gorillas' in 2015*". These learning activities foster students to explore how AI can impact society in both positive and negative ways, and related ethical issues so that students could incorporate the ideas into their stories.

After DSW processes, we asked students whether they gained understanding on AI ethics, and how they perceive AI ethics in their stories. In the interviews, four students claimed that they did not realize the importance of AI ethics in the past but now they knew the importance of data bias and ethical concerns in AI applications. For example, students demonstrated their understanding with some examples in their digital stories such as AI-driven automatic vehicles and criminal justice systems. A student named Trinity said, "*Refer to my story Future Trip, the superheroes and good robots have AI-related functions such as voice-over and transcription. Bad enemy robots imply the misuse of AI and have potential to cause data bias. Accidents and disasters may occur.*" We then asked her what types of accidents could occur when people misuse AI technologies. She gave an example of an AI-driven robotics car and continued,

Fig. 1. Examples to stylish photos into an artwork (https://deepart.io).

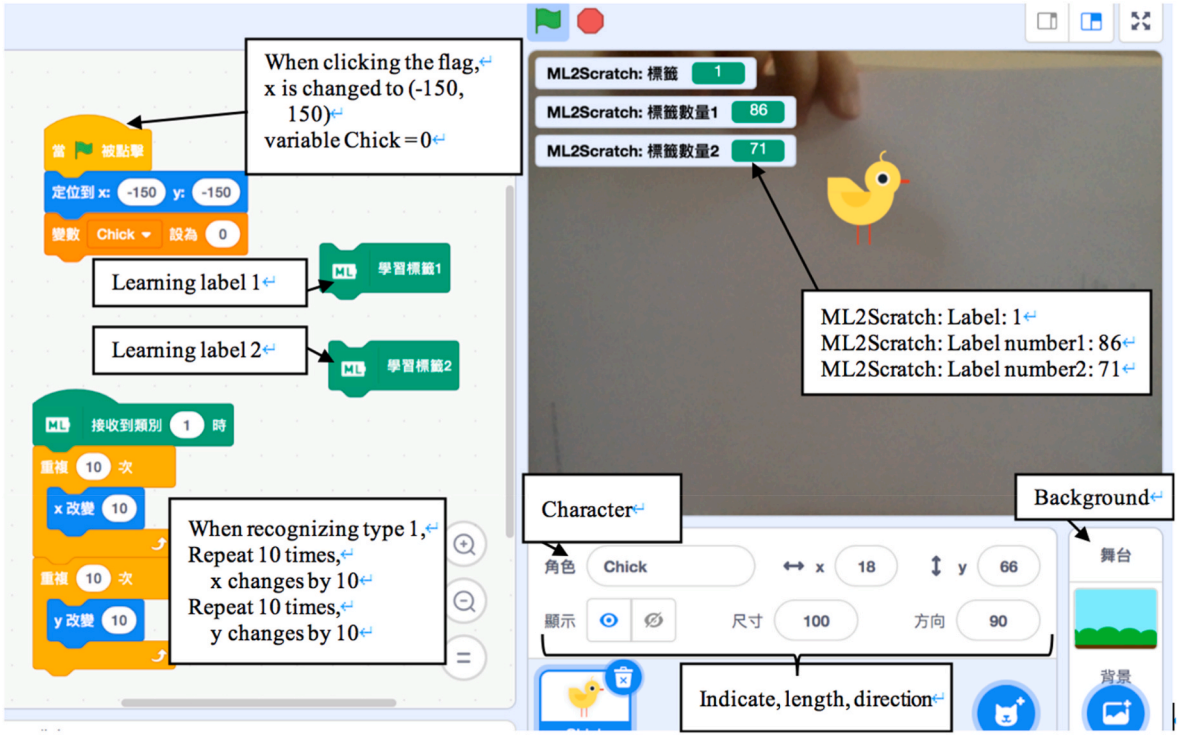

Fig. 2. Screenshot of building a machine learning model in Scratch.

"*People need to handle AI with care; otherwise, it will cause danger. AI can recognise red and green colours. However, when an AI automatic car recognized the colour wrongly, traffic accidents could happen. It must be designed carefully and accurately.*" Another student Max stated, "*We should not use information (e.g., gender, country) to build a model to determine whether a suspect should be sent to jail. This may cause data bias.*" Overall, students demonstrated that they could develop and apply safety and security practices to avoid unintended consequences that create risks of harm. Developing AI systems should be appropriately cautious and computer scientists should develop them in accordance with effective practices in AI safety research.

Besides, all sixteen students demonstrated in their stories that AI should benefit people to have a better living. Two of them showed their concerns that uncontrolled AI-driven robots would take over the human world and misuse of AI would cause destructive consequences such as taking revenge on humans and recovering extinct species like dinosaurs. A student Tse mentioned that governments need to set up laws for AI robots to control them from doubting humans' decisions and destroying people. Ethical principles for computer scientists should be developed to maintain trust and authority to make sure the AI robots are well-functioning and reduce potential risks. Furthermore, eleven students designed AI robots to solve authentic problems such as reducing ocean pollution, saving endangered species and healthcare crises. For example, Kong and Yi wrote that robots are human companions which use machine learning models to create different classes to play Kung Fu (pose recognition), make sushi (recommendation engine), classify planets with children (image recognition). Max wrote about a robot guard with a camera, wheel shoes and cannons that can use facial recognition to prevent strangers from entering the building and catching thieves to keep the residents living there safe. Hai suggested a waiter and chef robots to release people's workload to cook food with different recipes whereas Sammy designed an elderly companion to help the elderly to do housework (see Fig. 3). All these examples demonstrated how students address different problems or even global challenges to build different practical AI solutions.

Overall, all 16 students believed that digital story writing could enhance their motivation and ability in knowing, understanding and using AI. They could successfully observe authentic problems, apply their prior knowledge and AI concepts in specific scenarios so as to create imaginative AI-driven solutions in their stories. Although students may know how to transform AI techniques such as image and pose recognition across different scenarios, they did not know how exactly they can make the real artefacts. In the instructional design, students understand the basic AI principles through age-appropriate simulations and games such as Quickdraw and image stylizers. They experienced how AI works but they had no practical experience of data training, developing a machine learning model, manipulating relevant hardware and writing programs. Without these hands-on experience, they could only tell the AI principles behind through story creation but hardly explain what types of machine learning techniques and programs they should adopt. As such, in the future, it is recommended that hands-on experience such as designing machine learning models, data training and writing programs to implement their ideas should be incorporated in the AI learning activities.

Furthermore, most students didn't exactly tell which AI ethical principles that their stories implement but all of them believed that AI systems should socially benefit people, society and the environment to maintain sustainable development and human wellbeing. Students consider potential development and uses of AI technologies in their stories ethically to solve different authentic challenges such as environmental issues and healthcare crisis as mentioned. They expanded their AI and multi-disciplinary knowledge to suggest solutions in a wide range of fields including healthcare, security, energy and entertainment.

4.2. *Q2. What inquiry-based learning processes did students demonstrate through the DSW learning activities?*

This study provided qualitative evidence regarding primary students' development of AI literacy and story writing practices throughout the three-month DSW journey. Besides teaching how students read and write their digital stories, instructors stimulated students' inquiry on AI concepts throughout the DSW journeys and encouraged them to express

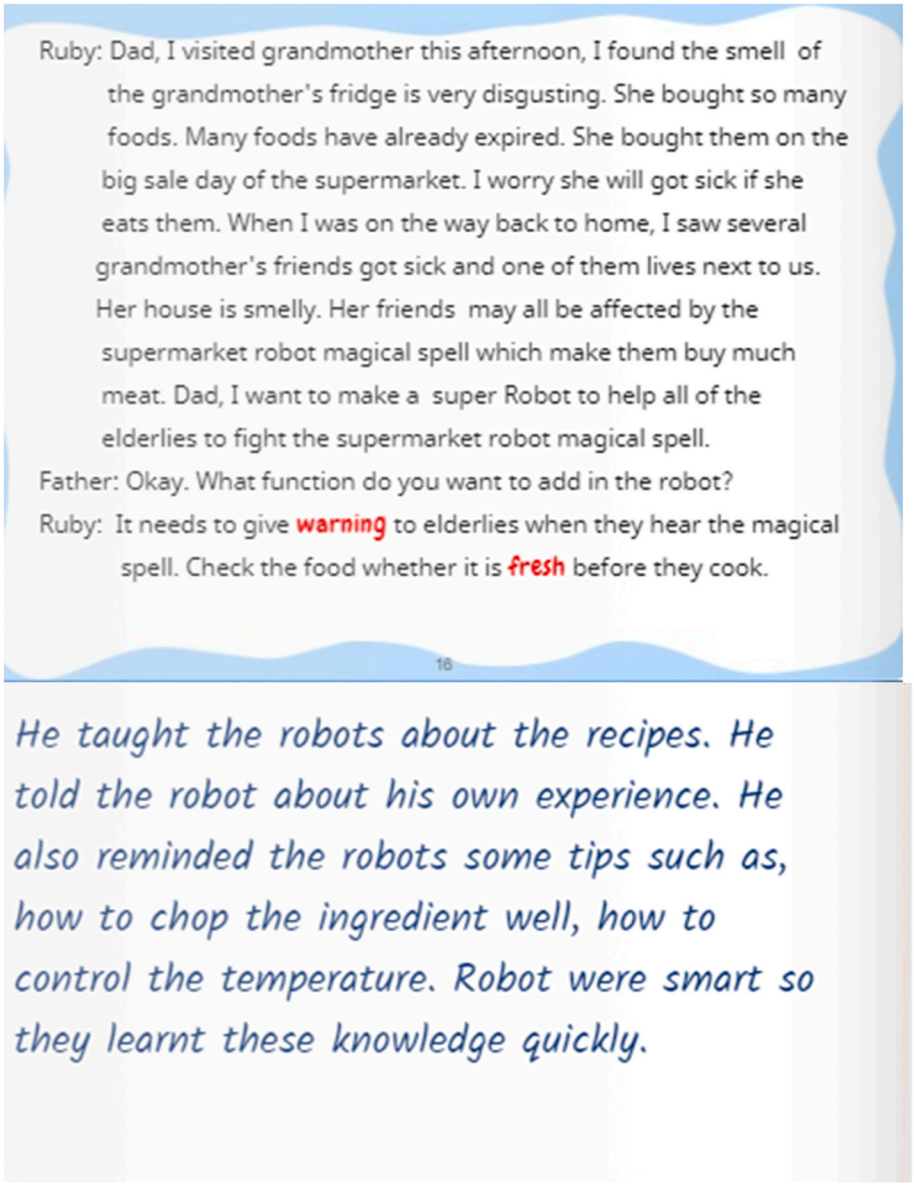

Fig. 3. Students' digital story about an AI-driven waiter and health alliance.

their ideas for proposed problems in their digital stories. Inquiry-based learning is gaining popularity in STEM-related curricula and development projects (Lai, 2018). In the context of AI literacy, recent AI-driven technologies (e.g., Quickdraw, teachable machine, Siri, translation) encourage students to discover new AI knowledge and applications via the inquiry process. The DSW process could not only encourage students to express their ideas, it also stimulates students' higher-order thinking skills and problem-solving to think forward. In this way, instead of knowing new concepts, students could reach a higher cognitive level to research and solve authentic problems that were raised in students' digital stories. To understand how students learn through the DSW learning activities, we used Pedaste et al. (2015)'s inquiry-based learning cycle to analyze students' DSW learning processes to develop their AI literacy via five phases: orientation, conceptualization, investigation, conclusion and discussion.

Phase 1: Orientation - Discovering AI.

Orientation is the process of stimulating students' curiosity to introduce a topic and addressing learning challenges through problems and explorative tasks (Pedaste et al., 2015). First, instructors introduced students to write a digital story with a topic "AI, Robots, Love and Peace". During the workshops, instructors provided students engaging activities including interesting videos, gamified tasks and online AI experimental tools to scaffold students' fundamental knowledge and build excitement and curiosity. Instructors facilitated students to explore AI knowledge through the online tools (e.g., AI Ocean at Code.org, Quickdraw, translation), and demonstrate how to solve problems by AI technologies (e.g., using image stylizer to draw a painting, using AI-driven robots to collect ocean garbage). They demonstrated students practical applications of how to use AI technologies to improve human's life and solve global challenges including environment and healthcare issues. This learning process could enhance students' critical thinking and problem-solving skills to connect their AI knowledge with real-world problems.

An instructor demonstrated some practical experience of using AI-driven tools to solve authentic problems in real-life scenarios. He told students, "*Nowadays, scientists and engineers design robots that use AI-vision to photograph floating objects and identify different types of marine plastic waste in the oceans to protect aquatic life.*" Then, students built a machine learning model to classify between garbage and fish in the ocean. Later in the presentation day, a student proposed the idea of

making a robot in her story to help recognise toxic garbage and non-garbage by using pattern and colour recognition. *"I borrowed the idea from the teacher to use AI robots to save the ocean. It's about how to recycle garbage and ocean pollution. The robots can recognise and recycle the garbage. People use data [such as patterns and colours] to train the model which helps humans to save the ocean."* From this story, we understand that students have applied machine learning concepts to connect to real-world situations and finally propose a solution to *save* aquatic life in the ocean (see Fig. 4).

After the AI learning experience, students are encouraged to read and comprehend AI-related comics and books, and watch self-learning videos to gain AI concepts in their leisure time. For example, teachers demonstrated how AI could recognise fish and further clean the ocean garbage which made a student to later write his story related to AI ocean cleaner (see Fig. 5). In addition, students connect their AI knowledge with their daily life experiences (e.g., using Siri and translation) at home and schools. All these provide a core foundation for students to come up with their own ideas in the next phase.

Phase 2: Conceptualization - Formulating problems.

Conceptualization is the process of generating questions and/or hypotheses to generate problems (Pedaste et al., 2015). The second phase conceptualization stimulated students to brainstorm with a writing plan of how they learn about their topics. Instructors asked students to come up with problems and develop possible AI-driven solutions to formulate their storylines. We asked students interesting questions to stimulate their thinking. Examples of questions are: Do you remember what kind of robot Baymax is? Do you know whether Captcha is AI-related? Can robots laugh and cry? How do people use AI robots to clean the ocean? How important love and peace are to humans when designing AI robots? Furthermore, our team developed online gamified quizzes through Kahoot! (a gamified platform) to check students' AI understanding. After stimulating students' thinking via interesting questions, gamified activities and, students decided that they would like to create stories about how AI robots could clean the ocean, interact with humans with facial expressions and become health companions like Baymax which is demonstrated in students' stories (Fig. 6a and b). All students claimed that they have done internet research to understand how AI could be applied to solve their proposed problems.

Phase 3: Investigation - Making inquiry through research.

Investigation is the learning process of planning exploration or experimentation, collecting and analysing data based on their exploration (Scanlon et al., 2011). In our DSW experience, students put together the proposed problem in the previous phase to further make inquiry and actively explore the writing topic through research, experimentation, exploration and observation. Throughout the research process, students have the opportunity to connect to real-world scenarios through observations and find solutions with teachers and parents. These learning activities stimulate students' inquiry to encourage students to continue their learning after lessons, which can be demonstrated in the interviews from students and parents.

In the program, teachers encouraged students to formulate authentic problems that could be solved by AI technologies such as healthcare and environmental issues. Students then made inquiries through exploring the AI-driven tools and tasks throughout the AI learning lessons. After the lessons, they continued their inquiries through observation, reading and asking questions. This learning process triggered students to gain a more in-depth understanding of AI knowledge so that they could create different AI-driven characters in their stories to solve their articulated problems. This way, students need to research and naturally express the AI knowledge in their stories through making inquiries, gathering information and expressing their views. For example, a student named Elva claimed she could explore the meanings of AI through educational videos, online tools and games: *"I enjoy the writing process. My school teachers haven't started to teach AI. My parents didn't know much about this field; they are not very tech savvy. When I have difficulties, I will search online and watch videos to find solutions. These online resources such as videos and games help me understand what AI is and enrich the content of my story."* Leung's mother claimed that the workshops taught students how to raise problems and articulate solutions through reading and searching on the Internet. She could learn much about AI in this DSW experience with her daughter. "*This is a research process. My daughter and I did not know much in this area. But while I'm looking for some interesting articles to read with my daughter, I can learn too. My daughter asked me questions and we searched for possible solutions on the Internet. She likes sharing what she knows with me too. The ideas totally originate from her though I help her organize her thinking to finally come up with her story.*" As such, reading, exploring AI-driven tools and discovering AI with parents are useful strategies that encourage inquiry-based learning.

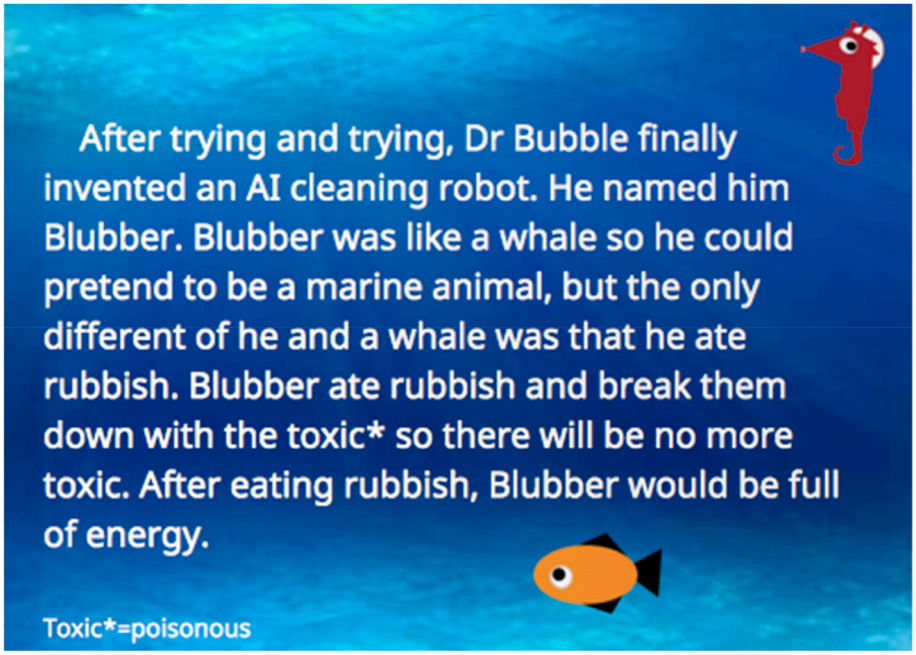

Fig. 4. Students' story to propose the use of AI to clean the ocean.

Fig. 5. Teachers' comics to illustrate how AI could recognise fish.

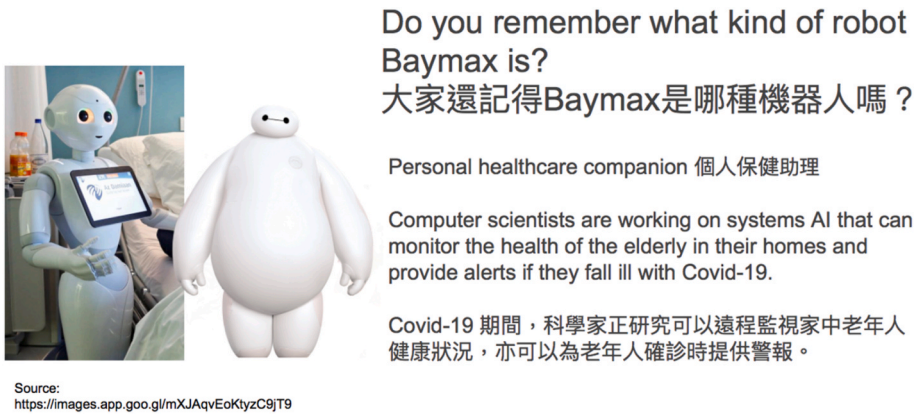

Fig. 6a. Teacher used Baymax as an example about an AI healthcare companion.

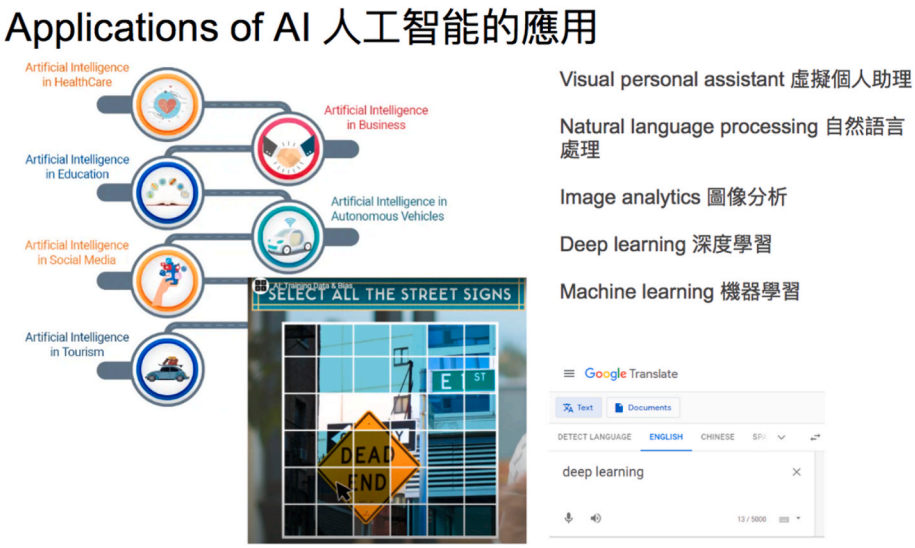

Fig. 6b. Teacher demonstrated different types of AI applications (e.g., education, business, translation).

Furthermore, collaborating with classmates to solve problems and figuring out solutions with teachers and parents are important. Students can further gain collective intelligence and collaborative innovation from their teachers, parents and classmates who inspire them to create their digital stories. For example, Chung's mother said, "*I study AI learning videos and information with my child. Throughout the learning*

process, when Chung doesn't understand the AI learning materials, I can try to explain to him and I can learn at the same time. My child and I realize that quite many technologies found in everyday life belong to AI applications too. In the past, we weren't aware of that." Another student Hin's dad said, *"I teach him how to use AI-related software … He sometimes observes me on how to learn using online platforms … I hope my active learning behaviour encourages him to use eLearning and computers or even AI-related learning tools to help his study too. As such, from my observation, he knows how to self-learn, use the Internet and find good resources to learn fast."* As such, we can see that active parental involvement is important when making inquiry to foster students' AI literacy.

"This year, I have attended a robotics making class, and a Scratch programming class. I know how to train the computers by taking many photos in front of a camera. I have learnt how to write programs to train a machine learning model with thirty pictures, and use microprocessors and sensors to recognise an object in AI-driven Scratch games and cars." As such, doing research and making inquiry would be important for students to further develop their AI concepts and make their work more convincing and interesting.

Phase 4: Conclusion - Creating stories and solutions.

Conclusion is the phase in which the basic conclusions of a project are stated (de Jong, 2006). In this phase, students addressed their original research problems and considered whether these are supported by students' research findings (Scanlon et al., 2011). They looked at the resources that they collected in the previous stages and transformed what they have learnt into students' final products. In constructing digital stories, students learnt to use technological tools and media to establish AI concepts through a digital story creation platform (Smyrnaiou et al., 2020). Students created digital stories with rich media artefacts that combined different multimedia elements such as a narrated audio text, animation and digital drawing (Boase, 2008). This combination of language, visual, and digital representations is a powerful cognitive tool to develop and express what students' have learnt in the 3-month writing journey. Students designed their digital stories with rich media elements such as a narrated audio text, animation and digital drawing.

A student believes that using digital story writing is an effective approach especially when creating digital stories, students could use multimedia creation tools which have some AI-driven applications. "*It's an interesting approach to let me know about AI through reading and story writing. I add cartoons and narratives for characters in the digital stories. When I use PowerPoint, I recognise the automatic style suggestion and Siri could also be AIs which are useful to make my eBook.*" A student's parent said: *"I work with my child to edit images and create digital content … He had difficulty in working with multimedia elements such as recording voice and creating illustrations. He tells me that Siri has voice recognition functions which could be AI"* Through this process, students find that they could use AI-driven tools such as PowerPoint style suggestions and Siri to help them design their digital stories.

Phase 5: Discussion - Communicating and reflecting on AI learning.

Discussion contains two sub-phases of communication and reflection in Pedaste et al. (2015)'s inquiry-based learning model. First, communication can be seen as an external process where students present their stories as the project outcomes to teachers and classmates, and receive feedback and comments from them (Scanlon et al., 2011), and sometimes listen to others and articulate their understandings (Bruce & Casey, 2012). Second, reflection is defined as an internal process of reflecting on and evaluating anything in the students' mind (e.g., What have I learnt? Why did I write this? What are the alternative options to solve the problem?). Discussions at the end of an inquiry should have students thinking forward via sharing and listening to each other's stories. Throughout this process, we invited every student to share their work and present their stories in front of classmates through web-conferencing software in real time and/or pre-recorded online video sharing. Teachers examined their work and facilitated the presentation and discussion. Students then reflected on their overall learning based on feedback from teachers and classmates.

One of the interviewees commented, "*In the past, I didn't realize that these technologies such as searching and recommendations could also have AI functions. After the training, I pay more attention than usual to recognise AI-related technologies in my daily life.*" Another student reflected, *"When I'm listening to others' stories, I learn that AI can impact society in both positive and negative ways. It makes me think of other possible solutions and endings to improve my story.*" A teacher observed that children could learn from each other through reading other digital stories and watching their presentations: *"The presentation is like a celebration for children to show their work. The learning environment is positive. All students can present their stories and use AI to solve the problem proposed in their books. At the same time, they reflect on themselves based on other work, and share their finalised stories and writing experience with teachers and classmates."*

Overall, inquiry-based learning is a meaningful approach to develop students' AI literacy that stimulates them to raise questions, ideas and observations. It gives students hands-on experience, methods and practices similar to those of professional scientists in order to construct AI knowledge. It can be defined as a process of discovering new knowledge, with the learner formulating hypotheses and testing them by conducting experiments and/or making observations (Pedaste et al., 2015).

5. Conclusion

Digital story writing has emerged as a powerful inquiry-based pedagogical tool across all disciplines by providing various direct and indirect advantages for the learners. This present study investigated the contribution of DSW as a pedagogy to develop four aspects of fostering AI literacy among upper primary students. We observed that all students perceived positively towards the DSW learning process and achieved up to higher cognition level. All of the stories demonstrated their understanding of AI concepts and skills (e.g., What is AI, supervised learning, neural network, AI-driven tools) and have reached the cognitive level of "use and apply AI". Through student interviews, some of them reflected the DSW experience on their everyday and school AI learning, and told us that DSW could facilitate them to evaluate and create AI artefacts by showing their AI creation such as computer programs and models that they built in their schools. On top of this, students could realize the importance of AI ethics and its social impacts such as algorithmic bias and consequences of misuse of AI through different learning activities.

In addition, we applied Pedaste et al. (2015)'s inquiry-based learning cycle to analyze students' DSW learning processes to develop their AI literacy via five phases (orientation, conceptualization, investigation, conclusion and discussion). First, we scaffold students' AI concepts and skills through hands-on activities such as Teachable Machine, image stylizing, translation. After exploring AI, students could formulate their problems and make inquiries through research. This involves students to search information, gather evidence, reflect on their experience, and present their knowledge in their own way. Ultimately, students could make up their stories and express their ideas using media and technologies in the digital story creation platform. They located and designed images and artefacts to make their text and content meaningful. This process requires students' critical awareness to convey the meaning of their stories and incidentally enhance students' media, technology and AI literacy.

The present study showed some limitations that need to be addressed in future research. First of all, the sample size was so small that only 16 students were interviewed and their work was analysed. The number of samples was less than one third of the total number in the DSW program. The qualitative artefact-based analysis provides us a comprehensive view of the primary students' development in AI through digital story writing. However, it may not provide generalizable results for a wider population, and future studies should broaden the sample. Furthermore, the results of this study might be subject to limited generalizability as

the interview and work analysis were implemented in selected groups who performed well in the program. Students with better performance could be more likely to develop their AI literacy than the other low-achieving students. In the future, we could also interview the low-achievers to tell us the challenges they met throughout the DSW journey.

Based on the outcomes of this study, the authors offer recommendations for educators to integrate future DSW and AI literacy courses and enhance students' learning performance. Firstly, reading and writing have been reconceptualized as effective ways to explore a knowledge domain enroute to acquiring new knowledge for decades (McGinley & Tierney, 1988). To foster students' AI literacy, teachers could engage them in reading AI-themed fictions and/or non-fictions, and hands-on experience such as tasting different AI-driven tools. After the activities, students could transform their knowledge and experience to story ideas in terms of writing purposes, genres, contents, audiences and roles. In this way, students can re-express their AI knowledge to model their scenes based on multiple sources including teacher, parent and classmate interaction, and the author/expert views learnt from their reading. On top of enhancing students' traditional writing skills, new literacy skills such as research via the internet, online communication and using (AI-driven) digital tools could reinforce student digital story creation.

On the other hand, pedagogies of digital story writing should be considered to facilitate students throughout their writing processes (Kearney, 2011). Before making their own books, brainstorming skills like observations, drawing (collaborative) mind maps, and sharing ideas with other people. During the writing process, students could build their narrative texts, produce the multimedia elements and format their books with a technological infrastructure including multimedia editing software and other AI-driven tools (e.g., proofreading, translation, artwork generation). At the end of the writing activities, teachers need to give formative feedback and assess their digital stories via presentations, demonstrations and video production, and further encourage students to refine and improve their work. Teachers can set up evaluation rubrics, examine students' understanding of AI concepts and skills, and explore their misconceptions from their stories by raising follow-up questions (e.g., What types of AI concepts have the students mentioned? How do you relate the content with the concepts? Why can the solutions solve the problem?) Third, communication and collaboration are important throughout the DSW and AI literacy learning. Teachers should formulate groups for students to share their views and co-construct their digital stories. They should mediate group discussions to extend their concepts and skill development. Moreover, a well-established online community like the platform we used in this study (Storyjumper) allows students (throughout the program or from outside) to appreciate each other's work and provide constructive feedback and ideas (Yamaç et al., 2020).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1. Interview protocol

A. Questions for parents

You are invited to participate in interviews to give valuable feedback on the AI Digital Story Writing journey. The questions prepared below are for interviewing parents:

1. How do you support your children to learn AI at home?
2. Can you comment on the STEM environment at your home? Do you encourage your children to learn/use AI outside the classroom?
3. What are the difficulties that you find in engaging your children in learning/using AI outside the classroom?
4. During the DSW journey, how do you enhance your children's AI knowledge? What/How's your role?
5. During the DSW journey, how do you facilitate your children to learn these concepts/support their writing processes?
6. Do you see any improvements in AI literacy among your children after the implementation of this project? If so, can you elaborate what they have learnt?
7. Based on your observation, what do your children benefit through this project by using digital story writing? What AI concepts have you learned when reading and creating stories? Are your children more interested in learning AI? (e.g., Knowing AI, Using AI, Creating with AI, AI ethics)

B. Questions for students

Students who are involved in this research will be invited to participate in interviews. The sample questions prepared below are for interviewing students.

1. Do you like learning AI? How do your teachers and parents encourage you to learn AI?
2. How about your classmates? Do they like AI too and do you enjoy writing AI stories and learning AI together?
3. What are the difficulties that you find to learn AI in this Digital Story Writing Competition?
4. Are you interested in learning AI?
5. Do you know what AI is? What AI concepts have you learnt in terms of knowing AI, using AI, creating with AI, and AI ethics.
6. Do you know how to use AI in everyday life? You may give one example.
7. Do you know how to evaluate and create things (e.g. story) with AI? You may give one example.

References

Ackermann, E. (2001). Piaget's constructivism, Papert's constructionism: What's the difference. *Future of learning group publication, 5*(3), 438–449.

Ahmad, M. A., Teredesai, A., & Eckert, C. (2020). January). Fairness, accountability, transparency in AI at scale: Lessons from national programs. In *Proceedings of the 2020 conference on fairness, accountability, and transparency*, 690-690.

Ashbrook, P. (2013). The STEM of inquiry. *Science and Children, 51*(2), 30–31.

Barber, J. F. (2016). Digital storytelling: New opportunities for humanities scholarship and pedagogy. *Cogent Arts & Humanities, 3*(1), Article 1181037.

Boase, J. (2008). Personal networks and the personal communication system: Using multiple media to connect. *Information, Communication & Society, 11*(4), 490–508.

Brennan, K., & Resnick, M. (2012, April). New frameworks for studying and assessing the development of computational thinking. In *Proceedings of the 2012 annual meeting of the American educational research association, Vancouver, Canada* (Vol. 1), 25.

Bruce, B. C., & Casey, L. (2012). The practice of inquiry: A pedagogical 'sweet spot'for digital literacy? *Computers in the Schools, 29*(1–2), 191–206.

Burgsteiner, H., Kandlhofer, M., & Steinbauer, G. (2016). March). Irobot: Teaching the basics of artificial intelligence in high schools. In *Proceedings of the AAAI conference on artificial intelligence* (Vol. 30), 1.

Chu, S. K. W., Reynolds, R. B., Tavares, N. J., Notari, M., & Lee, C. W. Y. (2021). *21st century skills development through inquiry-based learning from theory to practice*. Springer International Publishing.

Creswell, J. W., Klassen, A. C., Plano Clark, V. L., & Smith, K. C. (2011). *Best practices for mixed methods research in the health sciences*. Bethesda (Maryland): National Institutes of Health, 2013.

Dougherty, D. (2012). The maker movement. *Innovations: Technology, governance, globalization, 7*(3), 11–14.

Druga, S., Vu, S. T., Likhith, E., & Qiu, T. (2019). Inclusive AI literacy for kids around the world. *Proceedings of FabLearn*, 104–111, 2019.

Eisenlauer, V., & Karatza, S. (2020). Multimodal literacies: Media affordances, semiotic resources and discourse communities. *Journal of Visual Literacy, 39*(3–4), 125–131.

Frazel, M. (2010). *Digital storytelling guide for educators*. Washington, DC: International Society for Technology in Education.

Ghallab, M. (2019). Responsible AI: Requirements and challenges. *AI Perspectives, 1*(1), 1–7.

Gong, X., Tang, Y., Liu, X., Jing, S., Cui, W., Liang, J., & Wang, F. Y. (2020). October). K-9 artificial intelligence education in Qingdao: Issues, challenges and suggestions. In *2020 IEEE international Conference on networking, Sensing and control (ICNSC)* (pp. 1–6). IEEE.

Green, L. S. (2013). Language learning through a lens: The case for digital storytelling in the second language classroom. *School Libraries Worldwide, 19*(2), 23–36.

Gubrium, A. (2009). Digital storytelling: An emergent method for health promotion research and practice. *Health Promotion Practice, 10*(2), 186–191.
Hafner, C. A., & Miller, L. (2011). Fostering learner autonomy in English for science: A collaborative digital video project in a technological learning environment. *Language, Learning and Technology, 15*(3), 68–86.
Hagendorff, T. (2020). The ethics of AI ethics: An evaluation of guidelines. *Minds and. Machines, 30*(1), 99–120.
Han, X., Hu, F., Xiong, G., Liu, X., Gong, X., Niu, X., … Wang, X. (2018). Design of AI+ curriculum for primary and secondary schools in Qingdao. In *2018 Chinese automation congress (CAC)* (pp. 4135–4140). IEEE.
Harrison, R. L., & Parks, B. (2017). How STEM can gain some STEAM: Crafting meaningful collaborations between STEM disciplines and inquiry-based writing programs. In *Writing program and writing center collaborations* (pp. 117–139). New York: Palgrave Macmillan.
Hill, S., & Grinnell, C. (2014). October). Using digital storytelling with infographics in STEM professional writing pedagogy. In *2014 IEEE international professional communication conference (IPCC)* (pp. 1–7). IEEE.
How, M. L., & Hung, W. L. D. (2019). Educing AI-thinking in science, technology, engineering, arts, and mathematics (STEAM) education. *Education Sciences, 9*(3), 184.
Hughes, J., Gadanidis, G., & Yiu, C. (2017). Digital making in elementary mathematics education. *Digital Experiences in Mathematics Education, 3*(2), 139–153.
Jobin, A., Ienca, M., & Vayena, E. (2019). The global landscape of AI ethics guidelines. *Nature Machine Intelligence, 1*(9), 389–399.
November Johnson, K. (2019). *AI ethics is all about power*. Venturebeat Insider - The Machine Making Sense of AI. Retrieved from https://venturebeat.com/2019/11/11/ai-ethics-is-all-about-power/.
de Jong, T. (2006). Scaffolds for scientific discovery learning. Handling complexity in learning environments. *Theory and Research*, 107–128.
Julie, H., Alyson, H., & Anne-Sophie, C. (2020). Designing digital literacy activities: An interdisciplinary and collaborative approach. In *2020 IEEE Frontiers in Education Conference (FIE)* (pp. 1–5). IEEE.
Kaeophanuek, S., Na-Songkhla, J., & Nilsook, P. (2019). A learning process model to enhance digital literacy using critical inquiry through digital storytelling (CIDST). *International Journal of Emerging Technologies in Learning, 14*(3).
Kandlhofer, M., Steinbauer, G., Hirschmugl-Gaisch, S., & Huber, P. (2016). October). Artificial intelligence and computer science in education: From kindergarten to university. In *2016 IEEE Frontiers in Education Conference (FIE)* (pp. 1–9). IEEE.
Kearney, M. (2011). A learning design for student-generated digital storytelling. *Learning, Media and Technology, 36*(2), 169–188.
Lai, C. S. (2018). Using inquiry-based strategies for enhancing students' STEM education learning. *Journal of Education in Science Environment and Health, 4*(1), 110–117.
Laurillard, D., Charlton, P., Craft, B., Dimakopoulos, D., Ljubojevic, D., Magoulas, G., … Whittlestone, K. (2013). A constructionist learning environment for teachers to model learning designs. *Journal of Computer Assisted Learning, 29*(1), 15–30.
Leahy, D., & Dolan, D. (2010). Digital literacy: A vital competence for 2010?. In *IFIP international conference on key competencies in the knowledge society* (pp. 210–221). Berlin, Heidelberg: Springer.
Lee, I., Ali, S., Zhang, H., DiPaola, D., & Breazeal, C. (2021). Developing middle school students' AI literacy. In *Proceedings of the 52nd ACM technical symposium on computer science education* (pp. 191–197). ACM.
Long, D., & Magerko, B. (2020). April). What is AI literacy? Competencies and design considerations. In *Proceedings of the 2020 CHI conference on human factors in computing systems* (pp. 1–16). ACM.
McGinley, W., & Tierney, R. J. (1988). *Reading and writing as ways of knowing and learning*. Center for the Study of Reading Technical Report. No. 423.
Ng, D. T. K., & Chu, S. K. W. (2021a). Motivating students to learn AI through social networking sites: A case study in Hong Kong. *Online Learning, 25*(1), 195–208.
Ng, D. T. K., & Chu, S. K. W. (2021b). Motivating students to learn STEM via engaging flight simulation activities. *Journal of Science Education and Technology*, 1–22.
Ng, D. T. K., Leung, J. K. L., Chu, K. W. S., & Qiao, M. S. (2021a). AI literacy: Definition, teaching, evaluation and ethical issues. *Proceedings of the Association for Information Science and Technology, 58*(1), 504–509.
Ng, D. T. K., Leung, J. K. L., Chu, K. W. S., & Qiao, M. S. (2021b). Conceptualizing AI literacy: An exploratory review. *Computers and Education: Artificial Intelligence, 2*, Article 100041.
Ng, T. K., Ng, H. L., & Chu, S. K. W. (2021). Engaging students in creative music making with musical instrument application in an online flipped classroom. *Education and Information Technologies*, 1–20.
Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic books.
Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., … Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review, 14*, 47–61.
Rodríguez-García, J. D., Moreno-León, J., Román-González, M., & Robles, G. (2020). Introducing artificial intelligence fundamentals with LearningML: Artificial intelligence made easy. In *Eighth international conference on technological ecosystems for enhancing multiculturality* (pp. 18–20). ACM.
Scanlon, E., Anastopoulou, S., Kerawalla, L., & Mulholland, P. (2011). How technology resources can be used to represent personal inquiry and support students' understanding of it across contexts. *Journal of Computer Assisted Learning, 27*(6), 516–529.
Smyrnaiou, Z., Georgakopoulou, E., & Sotiriou, S. (2020). Promoting a mixed-design model of scientific creativity through digital storytelling—the CCQ model for creativity. *International Journal of STEM Education, 7*(1), 1–22.
Uccelli, P., Galloway, E. P., Barr, C. D., Meneses, A., & Dobbs, C. L. (2015). Beyond vocabulary: Exploring cross-disciplinary academic-language proficiency and its association with reading comprehension. *Reading Research Quarterly, 50*(3), 337–356.
Vazhayil, A., Shetty, R., Bhavani, R. R., & Akshay, N. (2019). Focusing on teacher education to introduce ai in schools: Perspectives and illustrative findings. In *2019 IEEE tenth international conference on technology for education (T4E)* (pp. 71–77). IEEE. December.
Wecker, C., Kohnle, C., & Fischer, F. (2007). Computer literacy and inquiry learning: When geeks learn less. *Journal of Computer Assisted Learning, 23*(2), 133–144.
Wong, G. K., Ma, X., Dillenbourg, P., & Huan, J. (2020). Broadening artificial intelligence education in K-12: Where to start? *ACM Inroads, 11*(1), 20–29.
Woo, M. M., Chu, S. K. W., & Li, X. (2013). Peer-feedback and revision process in a wiki mediated collaborative writing. *Educational Technology Research and Development, 61*(2), 279–309.
Wu, F., Lu, C., Zhu, M., Chen, H., Zhu, J., Yu, K., … Pan, Y. (2020). Towards a new generation of artificial intelligence in China. *Nature Machine Intelligence, 2*(6), 312–316.
Yamaç, A., Öztürk, E., & Mutlu, N. (2020). Effect of digital writing instruction with tablets on primary school students' writing performance and writing knowledge. *Computers & Education, 157*, Article 103981.
Yang, Y. F. D. (2012). Multimodal composing in digital storytelling. *Computers and Composition, 29*(3), 221–238.
Yuksel, P., Robin, B., & McNeil, S. (2011). Educational uses of digital storytelling all around the world. In *Society for information technology & teacher education international conference* (pp. 1264–1271). Association for the Advancement of Computing in Education (AACE).
Zhang, M., & Quintana, C. (2012). Scaffolding strategies for supporting middle school students' online inquiry processes. *Computers & Education, 58*(1), 181–196.