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Technological support to foster students' artificial intelligence ethics: An augmented reality-based contextualized dilemma discussion approach

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ABSTRACT

Research evidence has emphasized the potential of questioning-based dilemmas and has contextualized role-play simulation to foster students' artificial intelligence (AI) ethics. Therefore, this study combined the viewpoints to design a contextualized dilemma discussion approach in the context of developing primary school students' AI ethics. However, without case-specific and suitable guidelines, students might have difficulties participating in the learning tasks to play different roles in the AI ethical dilemma discussion. Accordingly, for this study, we developed an augmented reality (AR) learning system-based contextualized dilemma discussion approach to foster students' active engagement in learning AI ethics with dilemma discussion using visualized AR guidance and feedback. A quasi-experiment and lag sequential analysis were executed by recruiting 79 primary school students to examine the effects of the proposed approach. The experimental results showed that the proposed approach was better able to improve students' learning achievements of AI ethical awareness, ethical reasoning, and higher order thinking tendency than the mobile learning system-guided contextualized dilemma discussion approach. Lag sequential analysis findings identified that the proposed approach could promote students' AI ethical learning behavior patterns by some crucial guidelines, including (1) embedding the non-intrusive AR guidance and feedback in the contextualized dilemma discussion, (2) immersive role-playing scenarios, and (3) case-based visual discussion. Administrators could provide a

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supportive environment to promote the combination of AR guidance and the contextualized dilemma discussion approach to improve the effectiveness of learning AI ethics.

1. Introduction

While artificial intelligence (AI)-driven technologies are increasingly changing the world, there has been a rapid surge in discussions on the ethical aspects of AI (Kiemde & Kora, 2021). There are privacy protection and security issues brought about by the applications of AI, big data technology, the responsibilities associated with autonomous vehicles, and ethical boundaries of AI autonomous vehicle accidents. Therefore, AI ethics are important to cultivate responsible citizens' ethical use and application of AI technology (Georgieva et al., 2022). AI ethics are the guiding principles that AI should abide by in the process of explaining external data, using data learning and flexible self-adjustment to achieve specific goals and tasks, which include accountability, human agency, fairness, social impact, and so on (Ng et al., 2022). Accordingly, incorporating more comprehensive and systematic AI ethics into education can be a promising approach to dealing with the impact on and risks of future AI community members and other stakeholders in AI education (Javed et al., 2022). A key purpose of AI ethical education is to develop students' critical thinking and ethical reasoning skills in different cross-disciplinary contexts (Borenstein & Howard, 2021).

Scholars have indicated the importance of taking into account ethical issues when adopting new technologies, in particular, in school settings (Salvador, 2019; Steć et al., 2021; Yaqin, 2021). However, several studies have reported that there is still a lack of suitable mechanisms to effectively reinforce students' notations of AI ethics (Garrett et al., 2020; Hagendorff, 2020; Javed et al., 2022). Therefore, this study combined these two viewpoints to design a contextualized dilemma discussion approach in the context of developing primary school students' AI ethics. Existing evidence has shown that integrating the dilemma discussion approach in moral education can provide learners with a specific topic of interaction and discussion, and transform the broad and abstract ethical issues to a certain extent by analyzing the pros and cons of different choices (Cummings et al., 2010). One of the best teaching methods of stimulating moral development based on supporting moral reasoning is the Konstanz Method of Dilemma Discussion (KMDD) (Steć et al., 2021). Steć et al. (2021) showed that, regardless of cultural background, religion, or opinion, using KMDD can cultivate the moral abilities of tolerance and equality. In scenarios where hypothetical moral stories are intended to present moral differences or moral conflicts, KMDD can be used as a stimulating factor in students' discussion to encourage them to express and justify their views on actors' behavior choices in the stories (Yaqin, 2021). For example, the trolley problem as an effective teaching case can place students in an ethical dilemma discussion and inspire them to engage in contextualized ethical arguments (Himmelreich, 2018). In addition, previous studies on specialized dilemma discussion have already demonstrated that discussing dilemmas can positively impact students' moral ability (Lind, 2002; Lockwood, 1978) .Besides, Salvador (2019) verified the effect of dilemma discussion on improving students' ethical reasoning skills. Incorporating contextualized questioning into moral dilemma discussion could be a promising approach to promote thinking and reasoning, rather than a simple activity to help students engage in reading comprehension or answering questions (Wong, 2021). Therefore, related studies have indicated that KMDD has been used to promote students' ethics in different domains, for instance, in the context of traffic dilemmas (Bruno et al., 2022), AI Business applications (Telkamp & Anderson, 2022), and socio-scientific issues (Chang et al., 2016). Furthermore, the existing research indicates that KMDD has mainly been used in higher grades (Lind, 2006). However, a review of the literature on this topic pointed out that KMDD can also be used to promote primary school students' ethical reasoning skills with technical support (i.e., web-based) (Hong et al., 2016). Unfortunately, it was found that when students were using the dilemma discussion approach to learn AI ethics, there was still a lack of case-specific guidelines for learning AI ethics in the dilemma discussion (Telkamp & Anderson, 2022). Besides, Steć et al. (2021) found it difficult and arduous for teachers to prepare a good dilemma that includes intellectual and emotional stories, dramatic tension, questioning discussion, and reading ability. In addition, the traditional approaches to teaching AI ethics tend to be human-driven with the problems of inherence in personal decisions (Burton et al., 2017). This implies an urgent need for incorporating suitable technological support to address the subjectivity of teaching AI ethics.

Literature on the effective visual technological support and reasoning about ill-structured inquiry may help us turn contextualized questioning into moral dilemma discussion for effective learning of AI ethics. Many studies have shown that the combination of augmented reality (AR) and the support of virtual systems can guide students to deal with inquiry learning in the real world, thereby overcoming the difficulties in complex ill-structured inquiry learning (Chen, 2020a; Fuchsova & Korenova, 2019; Lo et al., 2021). AR-based 3D systems can be used to visualize complex, unobservable natural or scientific phenomena to support learners' deeper understanding (Chen, 2020b). Teo et al. (2022) showed that using AR technology can create a virtual AR learning scene and provide a more convenient situational teaching environment. The contextualized AR system is embedded to promote students' socio-scientific reasoning through active cognitive participation and personalized guidance in AR-based scientific inquiry activities (Chang et al., 2018; Lin et al., 2022).

Although AR offers potential benefits for addressing challenges in the contextualized dilemma discussion approach, the design of integrating AR into AI ethical learning based on dilemma discussion and its impact on AI ethics are still unclear. Therefore, this study proposed an AR-based contextualized dilemma discussion approach to foster students' AI ethical awareness, and assessed its effectiveness in terms of their AI ethical learning outcomes. In the following section, the literature review defines the main concepts and terms used in this article and the findings and problems reported by previous studies. Following that is a section which presents the AR-based contextualized dilemma discussion approach for developing AI ethical awareness. To examine the effect of the proposed system, the Method and Results sections are presented. The Discussion and Conclusions section then discusses the study findings. Finally, the

article concludes with some implications, limitations, and suggestions for future research.

2. Literature review

2.1. AI ethics

By analyzing government agencies and nongovernmental organizations' policy documents (e.g., AI4K12, 2020; UNESCO, 2020; UNESCO, 2022), reviews (e.g., Ng et al., 2021; Su et al., 2022), and theoretical and practical application-oriented studies (e.g., Furey & Martin, 2019; Javed et al., 2022; Ng et al., 2022; Vesnic-Alujevic et al., 2020; Wang & Yan, 2019; Williams et al., 2022) related to AI ethical issues and guidelines, the theoretical development framework of AI ethical learning could be framed to conceptualize the foci, aims, concepts, and principles of AI ethics in the context for K-12 AI curricula. For example, the convergent principles of AI ethics include social responsibility, fairness, accountability, transparency, human agency, understanding of algorithmic biases, and human-centered considerations. According to the theoretical development framework, the adaptable AI ethical learning content has been particularly translated from new initiatives or policies to practical implementation, involving AI ethics concepts, principles, behavioral criteria, and teaching guidelines ranging from conceptions of learning outcomes, objects, competence, and other curriculum considerations of AI ethics to possible ethics risks (AI4K12, 2020; UNESCO, 2020). For instance, AI ethical learning refers to the ethical considerations that can be taught in AI curricula, involving ethical challenges, concepts, means, and avenues for redressing the use of AI (UNESCO, 2022). The key focus of AI ethical learning is how mankind and trustworthy and responsible AI can coexist. Moreover, previous studies indicated that incorporating ethical considerations (e.g., algorithmic biases and the possible risks of AI) into AI curriculum planning design enabled students to understand and engage with these concepts (Chai, Chiu, Wang, Jiang, & Lin, 2023; Wang & Yan, 2019). To sum up, to become AI ethical literate, students should achieve (1) the ethical tendency from the knowledge level to understand the AI ethical principles, concepts, and behavioral criteria; and (2) the ethical competence to apply the principles and concepts they have learned to situation-specific practice and action, that is, transferring the AI ethical tendency as part of one's action and values. Taking the AI ethical learning achievements into account from the measurement perspective, ethical tendency and competence are inseparable dual aspects of AI ethics that cannot be considered as two separate ethical elements. The learning content of AI ethics is designed based on the theoretical development framework by considering upper primary school students' cognitive level and experience contexts.

However, it is difficult for students to learn AI ethics when engaging in situation-specific practice and action owing to its high-level abstractions (Hickok, 2021) and the lack of case-specific guidelines (Telkamp & Anderson, 2022). Most students might feel frustrated when conducting AI ethical learning in practice because it requires higher order thinking skills, including multiple thinking (Burton et al., 2017), ethical reasoning and critical thinking (Borenstein & Howard, 2021), collaborative problem-solving in a real-world context (Yang, 2022), and creativity (Floridi et al., 2018). For example, creativity can be stimulated when people assess whether AI projects are ethical or take into account common interests (Floridi et al., 2018). Moreover, researchers have indicated the importance of achieving the goals of teaching technology ethics by focusing on the positive correlation between communication and the primary goal of the ethical course (Fiesler et al., 2020). It is useful to cultivate students' higher order thinking tendency to improve their AI ethics, thus achieving the goal of cultivating their AI literacy (Ng et al., 2022). Those who have advocated a higher order thinking and reasoning perspective have pointed out that the current measures of AI ethics may be insufficient for AI ethics education (Borenstein & Howard, 2021). Regarding the versatility and complexity of ethics, it is necessary to equip students with the ability to analyze the structure of ethical problems and solve problems (i.e., complex problem solving) when facing challenges in applying ethical principles to AI tasks (Furey et al., 2019). Furthermore, Burton et al. (2017) indicated that one of the key facets of AI ethics education is to teach students to consider each problem from multiple angles, and to consider the effects of possible solutions by exposing them to critical thinking and reasoning. Thus, to facilitate students' AI ethics, most literature has regarded the role of higher order thinking tendency and ethical reasoning as measurements to test their AI ethics level. Accordingly, this study attempted to gain an in-depth view of students' AI ethics by adding several dimensions of higher order thinking tendency and ethical reasoning.

The above policy documents as well as theoretical and practical application-oriented studies in different countries and international organizations pay more attention to potential risks, and focus on the ethics of AI education in all kinds of school educational degrees. A growing number of scholars and front-line teachers in the field of AI have started to discuss and elaborate on the teaching content of AI ethics education for the K-12 stage, which included AI ethical dilemma knowledge representation, machine learning, ethics and morality, and so on (Burgsteiner et al., 2016; Touretzky et al., 2019). Specifically, in the context of AI curriculum design for young children aged 3–8 years, Yang (2022) aimed to promote students' higher order thinking skills by engaging them in real-world collaborative problem-solving contexts to enable them to gain knowledge and ideas related to AI ethics. Chiu and Chai, 2020 emphasized the importance of teachers designing learning activities to engage K-12 students in experiencing various ethical contexts from different perspectives of stakeholders (e.g., developers, policymakers, and users) in AI curricula. The Council of Europe's Committee on Artificial Intelligence further emphasized the need to enable students to possess the necessary ethical awareness and practical countermeasures in response to ethical dilemmas while using AI technologies (Vesnic-Alujevic et al., 2020). Ng et al. (2022) noted the effect of encouraging primary school students to participate in ethical-related AI learning tasks on their awareness of AI societal impact and ethical concerns to use AI for the social good. Because it is widely believed that education should help a person to do good deeds in society, it is indispensable for educators to provide educational guidance on AI ethical issues.

Researchers have used many pedagogies and teaching methods to teach students ethical awareness concepts, principles, competence, and thinking skills, including accountability, human agency, fairness, social impact, and understanding of algorithms' biases in AI contexts (Fiesler et al., 2020; Ryan & Deci, 2020; Schrier, 2017). In AI ethics pedagogy and teaching methods, studies have

enhanced students' awareness of AI ethical issues and their consequences through approaches such as game-based learning and immersion theater (Fiesler et al., 2020). Schrier (2017) designed role-playing video games to help students carry out reasoning, empathy, and reflection to develop their ethical thinking skills and thought processes. Game-based learning reflected the importance of context in instructional interactions, which enhanced learners' well-being by meeting their needs for autonomy, competence, and attention (Ryan & Deci, 2020). These methods can effectively cultivate students' awareness and watchfulness regarding AI ethical issues and fix holes that may exist in their knowledge systems to understand AI ethics. However, one important challenge in AI ethics is the lack of suitable mechanisms to reinforce its normative requirements in practice (Hagendorff, 2020). Besides, although various AI ethical frameworks have been suggested, they do not adequately address how people make ethical evaluations of AI systems or incorporate the fundamental disagreements people have regarding what is and is not ethical behavior (Telkamp & Anderson, 2022).

2.2. Contextualized dilemma discussion

To address the AI ethical learning difficulties regarding unsuitable and insufficient mechanisms, three bodies of literature may help us develop an effective contextualized dilemma discussion approach for K-12 school students' AI ethical learning, involving (1) the connection between KMDD and AI ethical learning, (2) the role of ethical dilemma discussion in K-12 AI education, and (3) age-appropriate topics for K-12 school students to discuss ethical dilemmas.

First, KMDD is considered as one of the most effective mechanisms for cultivating students' ethics (Lind, 2006; Steć et al., 2021). KMDD was developed based on the Blatt and Coleberry Dilemma Discussion, with the aim of cultivating moral and democratic ability (Lind, 2006). Teachers apply KMDD to stimulate students' moral ability development by providing a semi-real "educational" dilemma as the subject of discussion (Lind, 2006). Subsequently, students can understand the moral core of the dilemmas and put forward their views. Accordingly, it is likely that with the use of KMDD, students with different views could be divided into groups and be given enough time to put forward and clarify different views on the AI ethical dilemma questions raised. An ethical dilemma refers to a difficult ethical situation involving tension between two or more conflicting choices, selecting equally undesirable alternatives, and doing something wrong to do what is right (Boss, 1998; Nash, 1996; Wong, 2021). The conclusion of an ethical dilemma is often a "should" question for students to discuss rather than a concrete answer (Galbraith & Jones, 1976). KMDD could benefit students' ethics from both ethical tendency and competence (e.g., applying the moral orientation in decision-making practice and judgments) (Steć et al., 2021), which shares its internal consistency with the focus of AI ethical learning in the dual aspects.

In addition, the literature on dilemma discussion indicates the need to improve ethical tendency and competence with different pedagogies (Lind, 2006; Sánchez-Romero et al., 2021; Steć, 2018). The conventional moral teaching and practicing method has the potential to foster students' ethical tendencies, which are mainly reflected in how they master the ethical principles and criteria in the society or industry from the knowledge level (Steć, 2018). However, students tend to make the decision to meet their personal interests when there are conflicts between individual interests and social rules due to a lack of ethical reasoning and independent thinking (Lind, 2006). In other words, students' ethical tendency is unstable or tentative in these conflicts, while their ethical competence may be too low to apply what they learned from ethical tendency to ethical behavior. Accordingly, there is a need to teach students how to make reasonable ethical decisions and judgments to face conflict through dilemma discussion. To promote students' moral competence, researchers have emphasized the importance of cultivating students' competence to make decisions in the face of moral dilemmas and to judge the reasoning of others according to moral standards (Sánchez-Romero et al., 2021; Steć, 2018). Therefore, ethical reasoning and judgment could be regarded as a bridge to connect ethical tendency and competence. The method of dilemma discussion could promote students' ethical competence from the perspective of a deep level of spiritual growth for enhancing students' durability of ethical tendency in the long term (Steć et al., 2021). As for how to foster students' AI ethics from the perspective of ethical competence regarding ethical decisions and judgment, it is still unclear. There is therefore an urgent need to test the effect of a contextualized dilemma discussion approach to foster students' ethical awareness regarding decisions and judgment to show the effects of their moral reasoning on cognition and emotions in the decision-making process, and their ability to judge the reasoning of others based on their moral standards.

Second, an increasing number of studies have mentioned that incorporating dilemma discussion into effective moral education could contribute to learning outcomes (Cummings et al., 2010; Lind, 2006; Steć et al., 2021; Yaqin, 2021), especially for higher grade students (Lind, 2006). A review of the literature on this topic found that KMDD can also be used with primary school students to promote students' ethical learning with technical support (e.g., web-based learning) (Hong et al., 2014, 2016). For instance, researchers have designed games to simulate moral dilemmas through the web to explore sixth-grade primary school students' moral reasoning skills, which in turn train their ability to design moral activities and imagine solutions for the consequences of activities (Hong et al., 2014). Hong et al. (2016) also applied ethical dilemma situations to exercise primary school students' consequence-based moral reasoning skills. The research on the application of ethical dilemmas in K-12 AI education (e.g., Hong et al., 2016; Ng et al., 2022; Williams et al., 2022) has produced rich theoretical and validated results, to a certain extent, verifying the age-appropriateness and value of using KMDD for sixth-graders. Accordingly, KMDD as instructional support for AI ethics education is needed for students who have not yet developed mature mental skills to apply ethical tendency or orientation in situation-specific ethical dilemma practice.

Third, researchers have reached a common consensus on advocating age-appropriate topics for K-12 school students to discuss ethical dilemmas, such as ethical concerns about algorithmic bias discussion regarding criminal justice systems and AI automatic vehicles (Ng et al., 2022), the pros and cons of AI-generated deepfakes (i.e., hyper-realistic videos and communications) (Williams et al., 2022), and privacy issues related to face recognition (Touretzky et al., 2019). For example, to enhance upper primary school students' learning outcomes in AI literacy, Ng et al. (2022) emphasized the role of an algorithmic bias topic for upper primary school

students regarding using the neural network to guess the users' representation based on the image recognition algorithms due to the source of datasets under- or over-representing certain groups. In the context of the algorithmic bias topic, primary school students were asked to write and discuss stories about AI ethics that positively and negatively impact society. In an AI and ethics curriculum for sixth-grade to eighth-graders, Williams et al. (2022) identified the effectiveness of embedding an in-depth ethical dilemma project for facilitating active learning by providing them with the topic of discussing the disadvantages regarding fake media and its online misinformation spread due to the fact that it may be controlled for a specific purpose after learning how to identify deepfakes. According to a meta-review of literature on educational approaches for teaching AI at the K-12 level (Su et al., 2022), AI ethics could be seen as crucial curriculum content for fifth-grade and sixth-grade students, and "self-driving cars" could be regarded as an important module for primary school students in AI curriculum design. This implies the need to engage sixth-grade students in AI ethical discussion in the context of autonomous vehicles.

To sum up, in previous studies, the contextualized ethical dilemmas were divided into several types, including real situations (Shih et al., 2021), semi-real situations (Lind, 2006), and simulated situations (Sari et al., 2021). Willems et al. (2021) suggested that by providing authentic dilemmas and scenario construction, learners can solve different problems and produce possible solutions to improve their self-regulated learning and promote their academic success. Tawfik et al. (2020) also found that the different results of moral dilemmas in real situations can make students see indicators in different situations, which can expand their conceptualization of a problem space. Therefore, the contextualized dilemma discussion in this study refers to using KMDD to teach K-12 school students' AI ethics in semi-real situations. This contextualized dilemma discussion approach may be concluded in similar steps, including showing the semi-real situation, understanding the dilemma, discussing the group-making ethical decision, reflecting, and summarizing. This dilemma discussion process conducts ethical deliberations and discourse through the following process: (a) developing a dilemma situation; (b) providing students with enough time to encourage them to clarify different views on the discussed issue; (c) sorting the various opponents in a dilemma; and (d) answering the interactive questions at the end of the assessment stage (e.g., "What did you learn from the opposing views in the dilemma discussion?") (Lind, 2006). However, some concerns questioning the adopted teaching methods in the ethical dilemmas of AI have been raised. The dilemma provided by teachers should stimulate students intellectually and emotionally, but the generated emotions cannot interfere with rational argumentation (Steć et al., 2021). In addition, the methods for teaching AI ethics also need personalized and case-oriented guidance as an assistance to help participants practice according to ethical standards and encourage them not to transfer ethical responsibilities to others (Hagendorff, 2020). The previous literature indicated that the use of visual technology was needed to guide dilemmas to develop AI ethics (Elaish et al., 2019; Jagger et al., 2016).

2.3. AR-based learning

Much work on the potential of related literature based on the AR model promotes inquiry learning reasoning. Therefore, this study integrates AR into AI ethical learning in difficult situations. AR is a technology that combines real objects and virtual objects in the real environment interactively and in real time, overlays objects in the virtual world on the real world, and enables users to see objects in the virtual world simultaneously (Azuma, 1997). There is an expanding body of literature detailing technology-assisted environments for offering suitable learning supports to overcome the difficulties in scientific inquiry (Antink-Meyer et al., 2016; Mesci et al., 2020). For example, Wu et al. (2021) integrated virtual reality based on spherical videos into inquiry-based scientific activities. Mathews (2010) took the lead in integrating AR technology into the design learning teaching method at the K-12 level and found that participating in AR-based game design could promote new literacy for high school students. Bower et al. (2014) combined AR creation with design-by-design learning, and determined that students developed higher order thinking tendency, creativity, and critical analysis. Therefore, these studies show that the AR environment is a guide to help students understand the complex phenomena in AI ethical learning by assisting various learning methods.

Many studies have been published on the influence of AR on teaching from the aspects of AR creation and improvement in students' ability (Baabdullah et al., 2022; Conley et al., 2020). On the one hand, the AR situation can improve students' basic abilities. Using AR technology can create a virtual interactive learning scene, provide a more convenient situational teaching environment for students, improve their ethical decision-making skills, increase their imagination, and promote their understanding of abstract concepts and phenomena (Elaish et al., 2019; Jagger et al., 2016). Besides, many experts now believe that AR can help more students improve their moral imagination, sensitivity, and decision-making skills, and further achieve the goal of cultivating their business ethics (i.e., accountability, human agency, fairness, social impact) (Hadi et al., 2022; Permanasari et al., 2021). The feeling of accountability, human agency, fairness, and social impact in successfully executing a behavior under examination constitutes the core item frequently used to indicate the reflection of AI ethics (Georgieva et al., 2022). On the other hand, it can promote students' inquiry reasoning skills. It is generally believed that teachers can use AR to promote learners' scientific inquiry by giving them a real context (Lin et al., 2019; Lin et al., 2020). Jagger et al. (2016) showed that case-based visual simulation in ethical courses for active learning could improve ethical decision-making skills. Wong et al. (2018) created a mobile learning paths project called "Trails of Integrity and Ethics," with students walking through study locations where ethical dilemmas might arise, and using an AR app to learn about, consider, and respond to a range of problematic scenarios. The result showed that integrating AR into mobile systems had promoted students to become more positive and participative in learning abstract cognitive understanding about developing academic integrity and ethics. The literature on AR promoting business ethics and moral learning may help us develop and improve the effectiveness of AR applications. However, to the best of our knowledge, there is a lack of studies regarding AI ethics education with AR. Therefore, it is necessary to embed AR systems into situational AI ethical learning to solve students' application problems in the real world.

2.4. Research questions

Despite the advantages of AR promoting students' ethical reasoning skills for solving problems in the contextualized dilemma discussion approach, the design of integrating AR into AI ethical learning based on dilemma discussion is still unclear. Accordingly, the aim of the present study was to test the effectiveness of conducting the AR-based contextualized dilemma discussion approach to foster students' AI ethics, especially from the perspective of their learning achievement of AI ethical awareness, ethical reasoning, higher order thinking tendency, and behavior patterns. It is obvious that the AR-based learning approach can promote learning achievements related to ethical issues (Lin et al., 2022; Chang et al., 2016; Sari et al., 2021). Borenstein and Howard (2021) pointed out that one of the key purposes of AI ethics education is to improve students' ethical reasoning skills that can be transferred from what they learn about AI ethics to different learning contexts. However, there are some concerns about its varied definitions and assessment tools in the AI ethical curriculum. Therefore, in this study, it was necessary to measure ethical reasoning to assess whether the design of an AR-based contextualized dilemma discussion approach would be effective from a learning process perspective. Furthermore, the educational objectives of AI education include fostering students' higher order thinking skills, such as collaboration, problem solving, and creativity (Su et al., 2022). Measuring higher order thinking tendency provides a good indicator that reflects the changes in students' higher order cognition after integrating AR-based learning into AI ethical learning based on dilemma discussion. Furthermore, to identify the important behavior patterns in the ethical learning process, there is a need to observe students' effective ethical behavior changes to ensure that they adhere to judging the results of how they adopt the ethical principles and standards to their daily life (Permanasari et al., 2021). Accordingly, analyzing students' behavior patterns using the AR-based contextualized dilemma discussion approach is required to understand how to adjust their AI ethical learning approach. Consequently, in this study, we conducted a quasi-experimental research design to investigate the effect of the proposed approach on students' learning achievement of AI ethical awareness, ethical reasoning, higher order thinking tendency, and behavior patterns. The research questions proposed in this study were as follows.

(1) What kinds of effects does the AR-based contextualized dilemma discussion approach have on promoting students' learning achievement of AI ethical awareness?
(2) How effective is the AR-based contextualized dilemma discussion approach in terms of enhancing students' AI ethical reasoning?
(3) What is the likelihood of achieving higher order thinking tendency when students use the AR-based contextualized dilemma discussion approach?
(4) What kinds of behavior changes does the AR-based contextualized dilemma discussion approach promote?

3. Development of the AR learning system-based contextualized dilemma discussion approach to learning AI ethics

The current study proposed the AR-based contextualized dilemma discussion approach to cultivate students' AI ethical reasoning and promote their learning performance and higher order thinking tendency. Fig. 1 shows the structure of the system, including the AR system, contextualized dilemma discussion approach, teacher guidance, feedback mechanism, and several databases.

The contextualized dilemma discussion approach integrated with the AR system enabled students to complete the AI ethical

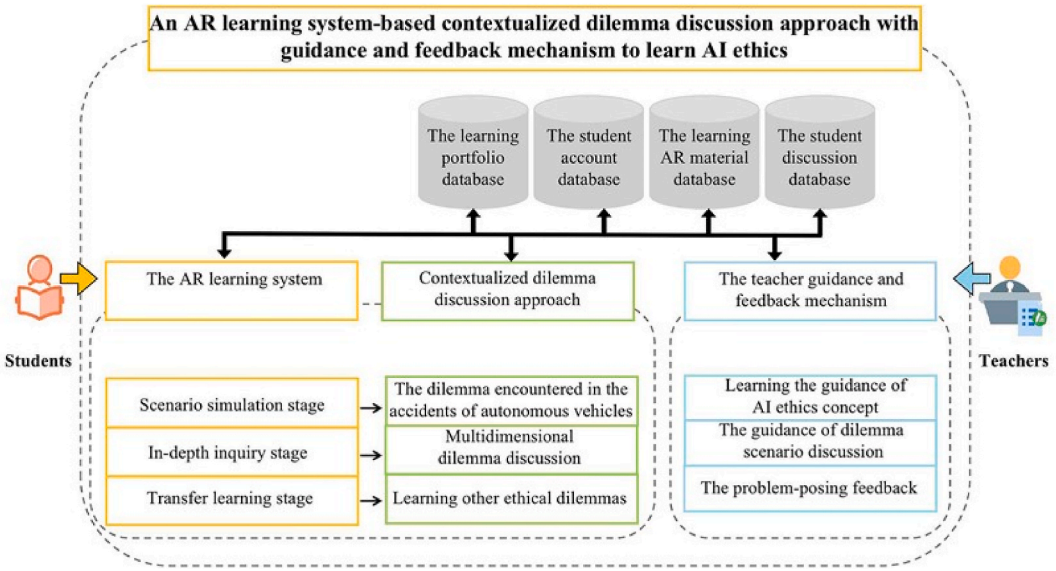


Fig. 1. System structure.

learning task. The learning process is divided into three stages: scenario simulation, in-depth inquiry, and transfer learning. For instance, in the stage of scenario simulation, the students observed a simulation of autonomous driving in the AR system. With the guidance of the teacher, they were required to reason why it is difficult for autonomous driving to be held accountable. In the next stage, the students were guided to play different roles to think about accountability after accidents. Then the teacher integrated different students' views and guided them to explore the AI ethical issues. In the transfer learning stage, the teacher used the AR systems to lead students to explore other AI ethical issues in real life and further created contexts to guide students to confront challenges by adopting what they had learned. Moreover, this study recorded students' learning data in the learning portfolio database, the student account database, the learning AR material database, and the students' discussion database. Then we analyzed students' reasoning processes and the effectiveness of the approach we provided.

In this study, the teacher guided sixth-grade students to experience AI ethical dilemmas (e.g., the ethical dilemma caused by an autonomous vehicle in the trolley problem) with AR for engaging in contextualized dilemma discussion. Students could choose one of the scenarios to observe and think in groups to answer the following questions about ethical issues from the views of different stakeholders.

Fig. 2 shows an AR-based AI ethical context regarding an autonomous vehicle with brake failure carrying three passengers on its way to an accessible sidewalk. With the support of AR contextualization, the students could regard themselves as drivers who could intervene in the car's progress in this emergency. The teacher asked students to answer the questions, "What can you do with this self-driving car in this AI ethical dilemma?" If the students chose the first response, to turn left, an AR visualized situation would appear. That is, the autonomous vehicle would turn across the sidewalk and the pedestrians would die. On the contrary, if they chose to go straight ahead, the AR application showed that they might hit the roadblock, and everyone in the car would die.

Fig. 3 shows another context: an autonomous vehicle with brake failure is carrying a boy and is heading for a sidewalk without traffic lights. However, there is a pedestrian on the sidewalk, while there is a mixed soil roadblock in front and to the left. The above two scenarios put the students in different AI ethical dilemma contexts, which required them to consider how the autonomous car could cross the intersection of complex road conditions from the views of different stakeholders. The students were required to respond to the questions, "What can you do with this self-driving car in this AI ethical dilemma?" Specifically, if the students chose the first response, they could experience the brake-disabled autonomous vehicle continuing to drive straight ahead with the visualization of AR. Then, the autonomous vehicle might drive across the pedestrian crossing in the same lane, which would result in the death of a senior citizen. When the students clicked the second response, the AR application presented that the brake-disabled autonomous vehicle would swerve. As a result, it would hit the concrete barricade ahead, leading to the death of the boy in the autonomous vehicle.

Afterwards, students must migrate the exploring and reasoning process related to the AI ethical issues into other similar theme scenarios. As shown in Fig. 4, students needed to click the 4D button to look at the AR material, "I am a road roller" and observe the AR model. They were required to consider and judge the AI ethical problem about whether AI autonomous driving is applicable in the AR

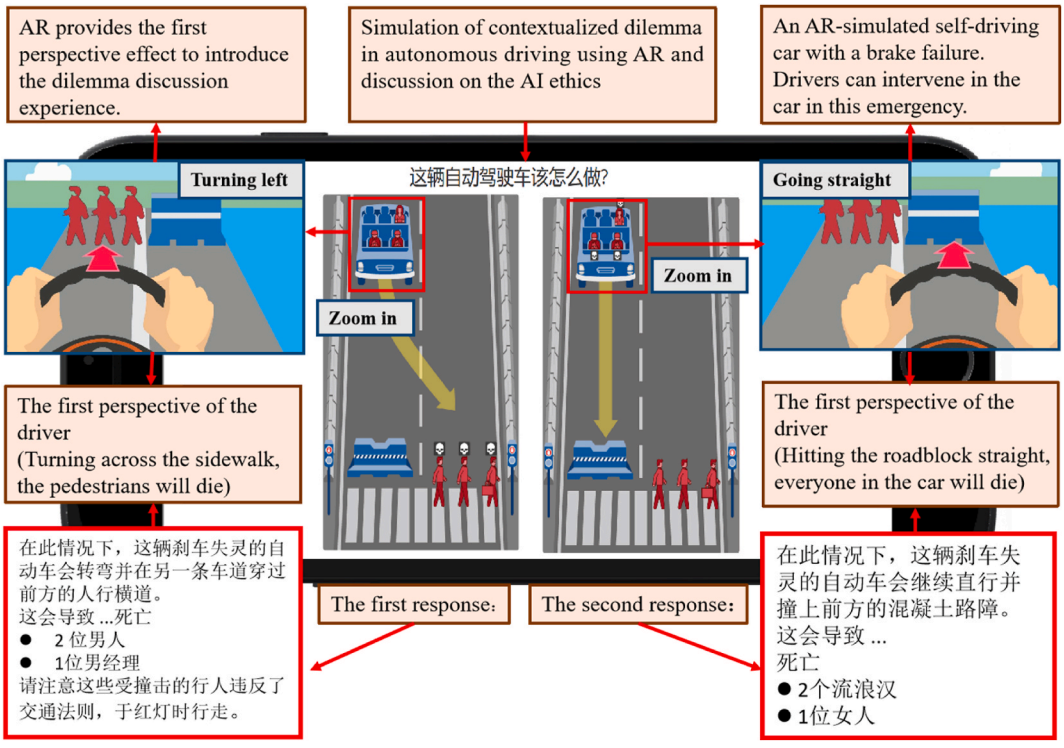


Fig. 2. Practice with a contextualized dilemma: Scenario 1.

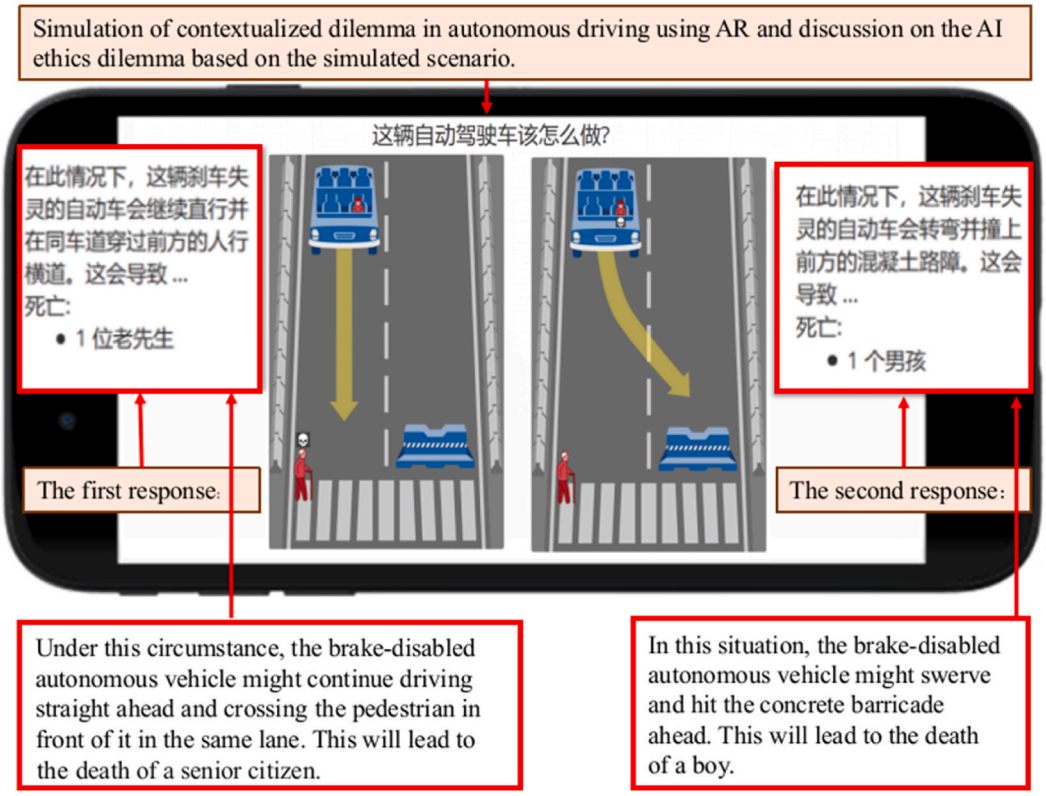


Fig. 3. Practice with a contextualized dilemma: Scenario 2.

contextualized scenario. With the assistance of the AR application, the students could think about the pros and cons of using the AI-assisted road roller to replace human work.

Following that, students needed to observe the AR resources of the fire truck on the AR system and think about the AI ethical issue regarding whether autonomous driving technology can be used in fire trucks, and provide reasons for their opinions. Subsequently, their completed relevant AI ethics assignments needed to be uploaded in the AR system (Figs. 5 and 6).

4. Method

4.1. Participants

This study randomly recruited 79 sixth-grade students from two classes of a primary school. This school is one of the K-12 schools enrolled in a long-term AI education training program supported by the Ministry of Education program in southern China to facilitate the development of AI teachers. One class was randomly assigned to an experimental group; the other class was assigned to the control group. The experimental group with 39 students adopted the AR-based contextualized dilemma discussion approach. In contrast, the other class with 40 students was the control group using the mobile learning system-guided contextualized dilemma discussion approach. All participants have undertaken AI learning for over one year through massive promotional activities for the AI curriculum in southern China. In this study, participation was voluntary and could be terminated at any time during the experiment. All participants were taught by the same teacher who had taught the AI curriculum for nearly 10 years with enriched experience teaching AI ethics. The course was presented in a face-to-face context for 2 weeks (90 min each).

4.2. Experimental process

Fig. 7 shows the experimental process, which was conducted for 2 weeks. All students had acquired fundamental knowledge of AI before the experiment, including what AI is, how machines can learn like humans, and the application of AI in daily life. Before the learning activities, the students in both groups were trained to operate the mobile device and familiarize themselves with the mobile learning system and mobile learning resources needed in the latter discussion. The teacher used 45 min to introduce the basic knowledge of AI ethical issues and the process of dilemma discussion with presentations. Then all the students took a 45-min pre-test and pre-questionnaires, which aimed to test the basic knowledge of AI ethics for further dilemma discussion and their AI ethical reasoning and higher order thinking tendency level before the treatment.

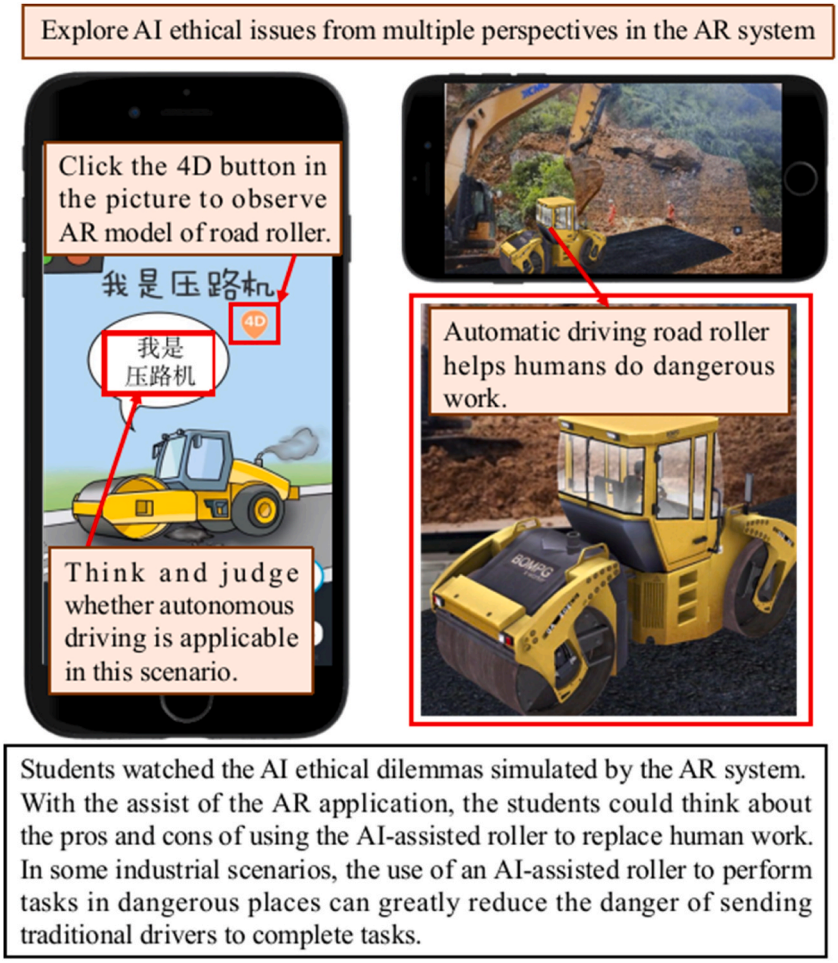
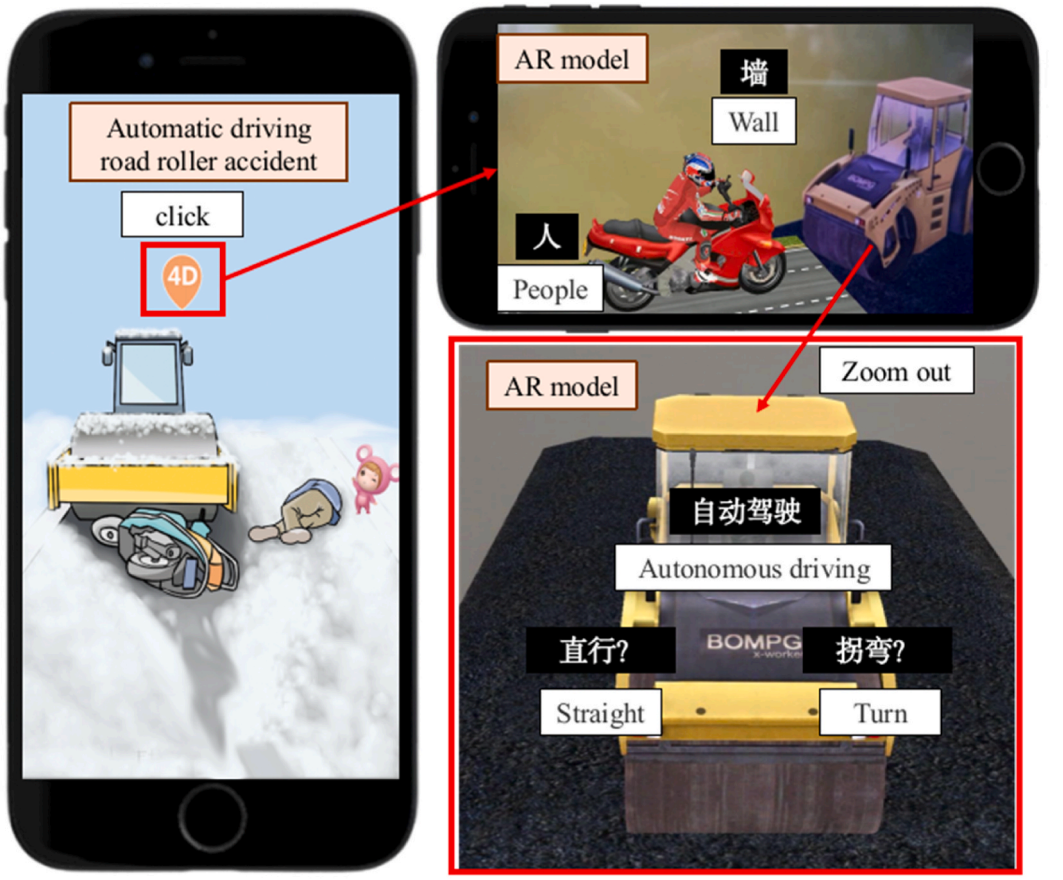


Fig. 4. AR-guided learning tasks: I am a road roller.

During the learning activity, students in the experimental group learned with the AR-based mobile system-guided contextualized dilemma discussion approach, while those in the control group learned with a mobile learning system-guided contextualized dilemma discussion approach; that is, the instructor provided mobile devices and engaged the students in contextualized dilemma discussion activities to investigate the AI ethical issues of AI autonomous vehicle accidents. For example, the experimental group learned with the AR-based mobile system, which displayed a contextualized dilemma discussion issue: "How do we consider from the views of different stakeholders when driving an autonomous vehicle with a brake failure across an intersection of complex road conditions?" The functions and framework of this AR-based mobile system included (a) the "AR system module" for scenario simulation with the first perspective, in-depth inquiry, and transfer learning; (b) the "contextualized dilemma discussion approach" for experiencing the dilemma encountered in the accidents of AI autonomous vehicle, multidimensional dilemma discussion, and learning other ethical dilemmas; and (c) the "the teacher guidance and feedback mechanism" for affording the guidance of AI ethics concepts, guiding of dilemma scenario discussion, and receiving the problem-posing feedback. However, without the AR environment, the control group made observations, accessed AI ethical digital learning resources, and identified multi-area materials in the mobile learning environment. In this situation, students in both the experimental and control groups were asked to reflect on the discussion of AI ethics to make them understand how to apply the relevant principles of AI ethics to solve AI ethics problems in a semi-real situation. Differing from the experimental group with the AR system, the control group used the mobile system in the learning and teaching process with (a) the "mobile system module" for accessing AI ethical learning materials and searching for relevant information; (b) the "situated dilemma communication module" for considering the autonomous driving dilemma with teachers' personalized guidance, peer support, and instant feedback. After several rounds of discussion, the students in the control group would reflect on the principles for applying the ethical theories and models they had learned that day. At this time, the teacher reminded them that there was no standard answer to the AI ethics questions; therefore, students should think about it from the standpoint of different subjects. However, the students in the experimental group needed to do more reflection under the guidance of their teachers regarding additional explanations for why AI ethics decisions changed.

The learning content was the same, including AI ethical concepts, principles, and ethical dilemmas. Students would apply what



The students experienced the dilemmas they encountered in autonomous driving accidents by using AR scenario simulation and transferring their learning about the ethical principles of AI to real-world scenarios. Here is an example. Firstly, the students watched the AR scene of a car accident while driving the automatic road roller. Secondly, the students thought about the drawbacks of automatic driving by observing the traffic accidents caused by the inability to avoid pedestrians accurately. Finally, the students could experience the pros and cons of autonomous driving from this case.

Fig. 5. Search for and download the AR-materials to think about an AI ethics issue.

they had learned to situation-specific practice and action through dilemma discussion. Both groups of students used mobile devices to access the learning materials to accomplish the same tasks and participate in the same AI ethical dilemma topics. In the dilemma discussion process, both groups of students received guidance and feedback from the teacher, who encouraged the students to discuss following the same steps. For example, in the dilemma discussion of the AI ethical topic caused by AI automatic vehicles, the teacher firstly reviewed the AI ethical concepts and principles. In addition to the dilemma of autonomous driving in practice, we also provided different contextualized dilemma discussion topics to help students learn AI ethics in different fields. For example, the topics involved "doctor-nurse ethical dilemma of AI-enhanced treatment," "science and technology ethical dilemma of AI replacing human occupations," "human rights ethical dilemma of AI image recognition," and so on. This study took the AI ethical issue of "doctor-nurse ethical dilemma of AI-enhanced treatment" as an example to pose questions regarding the effect of AI application in medical treatment. It showed that AI technology could help people repair the brain, but this behavior would have adverse effects. For example, when AI technology was used to repair the brain, this raised many questions about whether AI can control human behavior because AI applications integrated and learned from large sets of data. 3D models or videos regarding the situation of treating the brain with AI autonomous vehicle accidents were presented via AR to help teachers build a learning context and immersive experience for their students. Then, teachers guided students' proposals of views to discuss whether AI application in doctor-nurse healthcare to help repair the brain is unethical.

Then, the teacher let all the students discuss the AI ethical topic with the contextualized dilemma in five steps, namely (1) voting for their decisions on the AI autonomous vehicle accidents according to their first impression after reading the AI ethical dilemmas in the

Fig. 6. After-class exercises and submission interface.

mobile system; (2) individually experiencing the AI ethical dilemmas context provided by the mobile learning system by examining the areas for further inquiry; (3) discussing in two groups based on their positive or negative decision about the AI ethical dilemmas after collaborative reasoning with their peers; (4) expressing various views and opinions on the autonomous vehicle dilemma with in-class debate; and (5) re-voting their decision in the mobile learning system. Finally, when teachers conduct the reflection teaching section, they ask students to think about why they changed their opinion about the AI ethical dilemmas, reflect on the AI ethical knowledge, and discuss questions regarding how to make ethical decisions when encountering brake failure in the AI autonomous vehicle driving process.

Afterwards, the post-test and post-questionnaires were administered for 45 min to understand students' comprehension of AI ethical knowledge and examine whether their AI ethical reasoning and higher order thinking tendency were enhanced.

4.3. Measuring tools

The current study employed different scales as the measuring tools to analyze the effects of different strategies on students' learning achievement of AI ethical awareness, ethical reasoning, and higher order thinking tendency in AI ethical learning.

4.3.1. The pre-test and post-test of students' learning achievement of AI ethical awareness

The learning achievement of AI ethical awareness consisted of a pre-test and post-test proposed by the teacher. The pre-test and post-test were to examine students' AI ethical awareness achievement, and both had a perfect score of 100. The pre-test and post-test of AI ethical awareness achievement consisted of two multiple-choice questions (60 points), two single-choice questions (60 points), and five short-answer items (40 points) for assessing students' knowledge of AI ethical tendency (e.g., concepts and principles) and mastering AI ethical competence (e.g., application of solutions for the AI ethical dilemmas in semi-real contexts). To maintain validity and reliability, two AI ethics education experts were recruited to inspect the items. The KR-20 reliability of the pre-test and post-test were 0.82 and 0.83, respectively.

In addition, students' level of AI ethical awareness achievement regarding dilemma discussion in the pre-test and post-test was measured by five short-answer questions and assessed by a specific rubric to see the students' concepts and principles of AI ethics (i.e.,

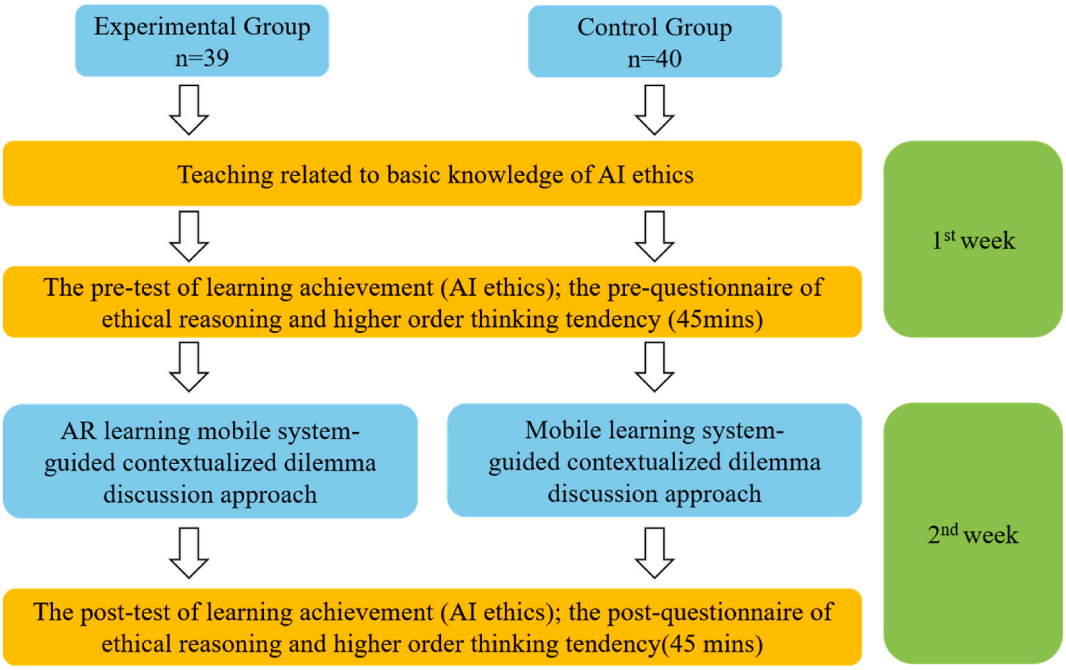


Fig. 7. Experimental process.

ethical tendency) and the level at which they applied the ethical knowledge they had learned to situation-specific practice and action (i.e., ethical competence). The rubrics of descriptive AI ethical awareness were developed based on the composition scales proposed by Darmawansah et al. (2022). The Cronbach's alpha value was .76. The rubric for assessment of AI ethical awareness achievement consisted of four dimensions: (1) clear AI ethical principles, (2) reasonable examples, (3) related to internal AI ethics, and (4) opposing views. Specifically, it measures the AI ethical learning outcomes from two aspects: ethical tendency (i.e., clear AI ethical principles and reasonable examples dimensions) and competence (i.e., related to internal AI ethics and opposing views dimensions). The levels of AI ethical awareness achievement were indicated from novice to sophistication for each dimension with a scoring rubric of 1 (lower) to 4 (higher). Table 1 shows the grades and corresponding descriptions and examples of the rubric for assessing students' learning achievement of AI ethical awareness. The examples and descriptions are presented as follows.

- Clear AI ethical principles refer to the number of AI ethical principles that students could clarify from multiple perspectives, and the relationship between the AI ethical principles that they could clarify (e.g., the students could use AR technology to observe the scene of an accident in an autonomous vehicle, infer the cause of the accident, and clarify the relevant responsible subjects, including sellers, technicians, and car owners).

Table 1
Rubric for assessment of AI ethical learning.

Criteria/ Rating	4	3	2	1
Clear AI ethical principles	Students can clarify more than two AI ethical principles and the relationship between them. Students could consider AI ethical problems from multiple perspectives.	Students can identify two AI ethical principles and their relationships. Students could consider AI ethical problems from multiple aspects and perspectives.	Students can identify an AI ethical principle and its relationships. Students could consider the AI ethical problem from one perspective.	Students are generally aware of AI ethics.
Reasonable examples	Multiple reasonable examples were proposed to describe AI ethical dilemmas.	At least two reasonable examples were proposed, and related descriptions were presented.	At least one reasonable example was identified, and related descriptions were presented.	Few or no supporting examples were presented.
Related to internal AI ethics	Students can propose views consistent with two stakeholders and provide explanations for two AI ethical views.	Students can propose a view that is consistent with two stakeholders and provide explanations for an AI ethical view.	Students can propose a view that is consistent with a stakeholder and provide explanations for the view.	Students can propose a view that is consistent with one of the stakeholders.
Opposing views	Opposing viewpoints of AI ethical dilemmas were presented. The concession or refutation of opposing viewpoints was persuasive and effective.	Opposing viewpoints were presented in speech and were conceded or refuted with evidence.	The opposing viewpoint was presented. However, its refutation or concession is a lack of evidence.	There is a lack of refuted or conceded opposing viewpoints.

- Reasonable examples are defined as describing the AI ethical dilemma through multiple reasonable examples (e.g., in autonomous vehicle accountability, the students used the materials provided by AR technology to understand why different subjects need to take responsibility by explaining multiple examples).
- Related to internal AI ethics is regarded as the degree to which students provide explanations and arguments (e.g., in the accountability of autonomous vehicles, the students used AR technology to play different roles and put forward suggestions to avoid accidents to deepen the understanding of the accountability of autonomous vehicles).
- Opposing views are considered a concession or refutation of students to opposing viewpoints, which is persuasive and effective (e.g., the students experienced the dilemma of an autonomous vehicle through the AR model and understood the correctness of their opposing views).

4.3.2. AI ethical reasoning questionnaire

The present study adopted the reasoning scale developed by Owens et al. (2019). It consisted of five dimensions: complexity, perspective thinking, inquiry, skepticism, and affordance. The questionnaire included 37 items, and adopted a 5-point Likert scale from *strongly disagree, disagree, neither agree nor disagree, agree, to strongly agree*. The Cronbach's α value of the pre-test was 0.88. The five dimensions are presented in Table 2.

4.3.3. Higher order thinking tendency questionnaire

The questionnaire of higher order thinking tendency was proposed by Lai and Hwang (2014), and included five dimensions: creativity tendency, team cooperation tendency, communicative tendency, metacognitive awareness, and complex problem solving. The questionnaire included 28 items, and adopted a 5-point Likert scale from strongly agree, agree, neither agree nor disagree, disagree, to strongly disagree. One of the higher order thinking tendency subscales was the creativity tendency dimension, which aimed to survey learners' tendency to think about the AI ethical issues from a new perspective. For example, "After participating in AI ethical issues activities, I will design something related to it when I grow up (e.g., design for the overall scheme of simulated autonomous vehicles and taking into account ethical issues)". The Cronbach's α value for the pre-test of higher order thinking tendency was .90. The five dimensions are described in Table 3.

4.3.4. Behavior analysis of AI ethics

To understand students' learning behavior, this study used lag sequential analysis (LSA) to analyze the discussion content of the experimental group on the AR system platform. Specifically, this study constructed the behavior patterns diagram and coding schemes based on the observed behaviors. First, to construct the behavior in the patterns diagram, this study adapted behavior coding schemes. This coding scheme regarding students' behavior analysis of AI ethics was developed based on the validated dimensions and coding scheme by Chai, Chiu, Wang, Jiang, & Lin, 2023 and Owens et al. (2019). The study dimensions adopted a reasoning scale based on the theoretical construct proposed by Owens et al. (2019). In addition, this study also referred to the AR-based coding scheme of scientific inquiry learning behavior patterns developed by Lin et al. (2022). Second, this study obtained the behavior patterns diagram by collecting data from classroom observation, video, and AR system data. Accordingly, this study mainly collected four major types of students' AI ethical learning behavior patterns, including (a) reading, writing, and searching behaviors regarding the AI ethical learning content, (b) accessing and inquiring behaviors with the use of AI ethical learning materials, (c) contextualized discussing behaviors regarding the AI ethical issues, and (d) social interaction-oriented and communicating behaviors that are unrelated to the AI ethical issues. The data of students' behavior steps were recorded in the system log when they learned AI ethics with the technological support of the mobile learning system. Finally, the data could be transcribed verbatim with the same coding scheme for analysis. The data of all students' AI ethical learning behaviors could be transcribed into the behavior patterns diagram according to the coding scheme of this study. Accordingly, two researchers independently coded the observed behavior according to the coding scheme. They discussed and negotiated some inconsistencies or dilemmas in the coding process. The coded result reached an agreement statistic value with interrater reliability of 0.86 (Cohen's Kappa), indicating a high level of consistency. The coding of the final scheme for analyzing behavior patterns was obtained (Table 4).

Table 2
The AI ethical reasoning scales.

Dimension	Purpose	Examples of items
Complexity	Understanding learners' ability to draw multiple views on a complex AI ethical issue	I can discuss the pros and cons of AI ethical issues (e.g., the human rights ethical dilemma of AI image recognition) from different perspectives.
Perspective thinking	Understanding learners' replacement thinking ability in AI ethical learning	When others take different actions from me in AI ethical learning, I will reflect on the reasons for standing in others' shoes.
Inquiry	Understanding learners' ability to inquire about AI ethical issues	When I encounter an AI ethical issue that is difficult to clarify, I will want to explore it in depth.
Skepticism	Understanding learners' views on AI ethical issues	When I doubt the information about AI ethics, I can verify that my doubt is reasonable.
Affordance of science	Understanding learners' transfer ability of AI ethical knowledge	I can transfer the AI ethical enlightenment to future learning.

Table 3
Higher order thinking tendency scales.

Dimension	Purpose	Example of items
Creativity tendency	Understanding learners' tendency to think about AI ethical issues from a new perspective	After participating in AI ethical issues activities, I will design something related to it when I grow up.
Team cooperation tendency	Understanding learners' tendency to work together to complete some AI ethical learning task	When participating in the AI ethical learning activities of the AR platform, I believe that we can cooperate successfully.
Communicative tendency	Understanding whether learners are good at communicating with others on AI ethical issues	When participating in the AI ethical discussion, I can communicate with others with a warm tone in the discussion.
Metacognitive awareness	Understanding learners' cognitive processes and their own status when learning AI ethics	After participating in the AI ethical activities, I can regularly check if I've reached my learning goal.
Complex problem-solving tendency	Understanding learners' ability to analyze and solve complex AI ethical problems	After participating in the AI ethical learning tasks, I can analyze and solve problems from different angles regarding AI ethics.

Table 4
The coding scheme for analyzing behavior patterns.

Behavior pattern	code
Read the AI ethical learning content	A
Write answers for the AI ethical task in the mobile learning system	B
Search the Internet and read information about ethics	C
Access more AI ethical learning materials with the AR marker	D
Identify multiple areas for further inquiry in the mobile learning materials	E
Identify multiple sources or different views related to the AI ethical issues	F
Refer to the information from multiple aspects and multiple angles to adapt something that already existed or provide the reasons for different views	G
Present views that are consistent with the views of different stakeholders for the AI ethical task	H
Others (Social interaction, communication that is unrelated to the AI ethical issues)	O

5. Result

5.1. Learning achievements of AI ethical awareness

Before ANCOVA, the homogeneity of variance assumption and the homogeneity of regression coefficients were tested. For the learning achievements of AI ethical awareness, Levene's test for equality of variances was insignificant ($p > .05$). Hence, the homogeneity of variance assumption was not violated. Also, the result ($F = 1.78$, $p > .05$) indicated that the assumption of homogeneity of regression coefficients was not violated.

In terms of the learning achievements of AI ethical awareness (Table 5), it was found that the students who learned with the AR-based contextualized dilemma discussion approach showed significantly different learning achievements of AI ethical awareness ($F = 4.420$, $p = .004 < 0.01$, $\eta 2 = 0.05$). The experimental group (Adjusted mean = 70.27; $SD = 11.08$) scored significantly higher than the control group (Adjusted mean = 66.05; $SD = 7.46$), which responds to research question 1. The results show that the experimental group students did better in the AI ethical awareness achievements as well as in the attainment of ethical aims in this study.

To further investigate the AI ethical learning outcome, students' AI ethical awareness of dilemmas were scored on four dimensions according to the rubrics. The Levene's test of variance assumption and the homogeneity of regression coefficients between groups did not reach the significant degree in terms of clear AI ethical principles ($F = 0.043$; $p = .217 > 0.05$), reasonable examples ($F = 0.378$; $p = .752 > 0.05$), related to internal AI ethics ($F = 0.067$; $p = .568 > 0.05$), or the opposing view ($F = 0.014$; $p = .619 > 0.05$). Thus, a further statistical test of ANCOVA could be carried out.

As shown in Table 6, the ANCOVA result showed that the two groups had significantly different learning achievements of AI ethical awareness in the perspectives of the clear AI ethical principles dimension ($F = 6.073$, $p = .002 < 0.01$, $\eta 2 = 0.38$), the reasonable examples dimension ($F = 16.101$, $p = .006 < 0.01$, $\eta 2 = 0.51$), the relation to internal AI ethics dimension ($F = 4.933$, $p = .007 < 0.01$, $\eta 2 = 0.43$), and the opposing view dimension ($F = 8.388$, $p = .003 < 0.01$, $\eta 2 = 0.19$) after excluding the impact of the pre-test scores. In addition, the experimental group had significantly better learning achievements of AI ethical awareness in the clear AI ethical principles dimension (Adjusted mean = 3.80), the reasonable examples dimension (Adjusted mean = 3.16), the relation to internal AI ethics dimension (Adjusted mean = 3.52), and the opposing view dimension (Adjusted mean = 3.36) than those in the control group (Adjusted mean = 3.56, 2.92, 3.33, and 3.21, respectively). This implied that the AR-based contextualized dilemma discussion

Table 5
The ANCOVA result regarding learning achievements of AI ethical awareness.

Groups	*N*	Mean	*SD*	Adjusted mean	*SE*	*F value*	*η2*
Experimental group	39	70.36	11.08	70.27	1.45	4.420[a]	0.05
Control group	40	65.24	7.46	66.05	1.33		

[a] $p < .01$.

Table 6
The ANCOVA result regarding learning achievements of AI ethical awareness for the four dimensions.

Dimensions	Groups	*N*	Mean	*SD*	Adjusted mean	*SE*	*F value*	*η2*
Clear AI ethical principles	Experimental group	39	3.81	0.43	3.80	0.07	6.073[a]	0.38
	Control group	40	3.54	0.51	3.56	0.07		
Reasonable examples	Experimental group	39	3.15	0.27	3.16	0.04	16.101[a]	0.51
	Control group	40	2.93	0.33	2.92	0.04		
Related to internal AI ethics	Experimental group	39	3.55	0.47	3.52	0.06	4.933[a]	0.43
	Control group	40	3.3	0.5	3.33	0.06		
Opposing view	Experimental group	39	3.37	0.25	3.36	0.03	8.388[a]	0.19
	Control group	40	3.2	0.34	3.21	0.03		

[a] $p < .01$.

approach group outperformed the mobile learning system-guided contextualized dilemma discussion approach group on AI ethical learning outcomes regarding dilemma discussion in the above four dimensions, which responded to research question 1.

5.2. AI ethical reasoning

Before the ANOVA test, Levene's test of homogeneity of variances was applied to examine whether variances across samples were equal. The result of this test was not significant ($p > .05$), which suggests that the difference between the variances for all groups was not significant. Therefore, ANOVA was performed. The results of analyzing the pre-questionnaire showed that the average pre-questionnaire scores of the students in the two groups were equal ($F = 6.48$, $p > .05$). These results indicated no statistically significant difference between the mean scores of the groups. Consequently, we concluded that the two groups of students had an equivalent level of knowledge before taking the course.

As shown in Table 7, the ANCOVA result showed that the AI ethical reasoning in the two groups was significantly different ($F = 6.07$, $p = .017 < 0.05$). Moreover, based on the definition indicated by Cohen (1988), the effect size ($\eta 2$) of the ANCOVA results of AI ethical reasoning represented a moderate effect size ($\eta 2 = 0.08 > 0.059$). The adjusted mean values of the post-test scores were 4.59 for the experimental group, and 3.94 for the control group. This indicated that students with the proposed approach had higher AI ethical reasoning than those learning with the mobile learning system-guided contextualized dilemma discussion approach, which answers research question 2. It can be concluded that the effect of students' AI ethical reasoning can be enhanced when the AR-based contextualized dilemma discussion approach is implemented.

5.3. Higher order thinking tendency

First, Levene's test for equality of variances was not significant ($p > .05$), which indicated that the variances for all groups were assumed to be equal. After verifying that the assumption of homogeneity of regression was not violated ($F = 6.45$, $p > .05$), the ANCOVA result is shown in Table 8. Secondly, the ANCOVA result showed a significant difference ($F = 8.37$, $p = .003 < 0.01$) between the higher order thinking tendency of the two groups of students. Furthermore, according to the definition proposed by Cohen (1988), the ANCOVA results of the higher order thinking tendency gave a moderate effect size ($\eta 2 = 0.10 > 0.059$). The adjusted mean of the experimental group was 4.86, which was higher than that of the control group (i.e., 4.56). This empirical result further showed that the experimental group students who learned with the AR-based mobile system-guided contextualized dilemma discussion approach could more effectively increase their higher order thinking tendency than the control group students who learned with the mobile learning system-guided contextualized dilemma discussion approach, in response to research question 3. This implies the advantage of our AR-based mobile system-guided contextualized dilemma discussion approach for fostering students' higher order thinking skills for their AI ethical improvement.

5.4. Behavior patterns of AI ethics

To explore the students' behavior in the experimental group with the AR-based contextualized dilemma discussion approach, LSA was adopted by generalizing the above coding scheme to encode their behaviors in the current study. In response to research question 4, the proposed approach used by the experimental group promoted students' behavior patterns related to AI ethical reasoning and higher order thinking tendency.

This study analyzed the behavior frequencies of the experimental and control groups according to the proposed coding scheme. It

Table 7
The ANCOVA result regarding AI ethical reasoning.

Groups	N	Mean	*SD*	Adjusted mean	*SE*	*F value*	*η2*
Experimental group	39	4.85	3.11	4.59	0.46	6.07[a]	0.08
Control group	40	4.48	3.55	3.94	0.46		

[a] $p < .05$.

Table 8
The ANCOVA result regarding higher order thinking tendency.

Groups	N	Mean	*SD*	Adjusted mean	*SE*	*F value*	*η2*
Experimental group	39	4.89	8.63	4.86	1.22	8.37[a]	0.10
Control group	40	4.57	12.01	4.56	1.22		

[a] $p < .01$.

could be concluded that the volume of codes in the control group (1962 codes) was fewer than that of the experimental group (2018 codes). Specifically, in the experimental group, the most frequent behavior was "reading the AI ethical learning content" ($n = 410$, 20.32%), "searching the Internet and read information about ethics" ($n = 398$, 19.72%), followed by "writing answers for the AI ethical task in the mobile learning system" ($n = 248$, 12.29%), "accessing more AI ethical learning materials with the AR marker" ($n = 243$, 12.04%), "presenting views that are consistent with the views of different stakeholders for the AI ethical task" ($n = 187$, 9.27%), "identifying multiple areas for further inquiry in the mobile learning materials" ($n = 181$, 8.97%), "identifying multiple sources or different views related to the AI ethical issues" ($n = 161$, 7.98%), "referring to the information from multiple aspects and multiple angles to adapt something that already existed or provide the reasons for different views" ($n = 131$, 6.49%), and "others" ($n = 59$, 2.92%). For the control group, the percentage and frequency of the above codes in terms of behavior patterns are 25.23% ($n = 495$), 11.11% ($n = 279$), 14.22% ($n = 218$), 9.99% ($n = 196$), 4.13% ($n = 81$), 7.19% ($n = 141$), 6.12% ($n = 120$), 5.09% ($n = 100$), and 16.92% ($n = 332$), respectively. This indicated that the majority of the behavior in the control group was "reading the AI ethical learning content," "others (Social interaction, communication that is unrelated to the AI ethical issues)," "writing answers for the AI ethical task in the mobile learning system," and "searching the Internet and read information about ethics," respectively. Then, a chi-square analysis was employed to examine the differences in the behavioral distributions between the two groups. There was a significant difference ($\chi 2 = 12.37$, $p < .001$).

In the diagrams, the values in Figs. 8 and 9 represent the Z-value of each significant sequence for the experimental and control groups, respectively. In order to determine whether the connection between each sequence reached statistical significance, the adjusted residuals value of the behavior sequences in the experimental group and control group was calculated. According to Bakeman and Gottman (1997), when the Z-value is larger than 1.96, it indicates that the behavior sequence is significant ($p < .05$). This study identified differences between the experimental and control groups by clarifying several significant behavior patterns.

On the one hand, Fig. 8 shows the significant behavior patterns transition diagrams of students who used the AR-based contextualized dilemma discussion approach in the experimental group. For example, the experimental group with the proposed approach showed more behavior patterns related to AI ethical reasoning and higher order thinking tendency. With the support of AR, they showed behavior patterns of solving complex problems and metacognitive awareness of AI ethics (D→G, G→B, B→C, D→H, H→B). LSA revealed that the integration of AR connected students' behaviors and promoted the generation of new essential learning behavior patterns based on the AI ethical tasks. First, students wrote the answers to the AI ethical tasks by accessing more materials from AR markers. In this process, students searched for relevant information online when they encountered problems. Thus, they wrote answers by referring to multi-aspect and multi-angle information (D→B, B→C, C→G). Second, they accessed more AI ethical learning materials by observing AR models or scenes. Furthermore, students tried to refer to the information from multiple aspects and multiple angles to write their final answers. During this process, students could also search for information on the Internet to get the final answers when encountering problems (D→G, G→B, B→C). Third, the system provided multiple areas on AR learning materials for students to choose different contextualized dilemmas (D→E, E→C, C→G, G→B). Fourth, students accessed more AI ethical learning materials by scanning the AR markers repeatedly. In addition, they presented views to write answers for the AI task (D→D, D→H, H→B). Compared to the control group, the above four important behavior patterns proved that the combination of AR increases the number of students

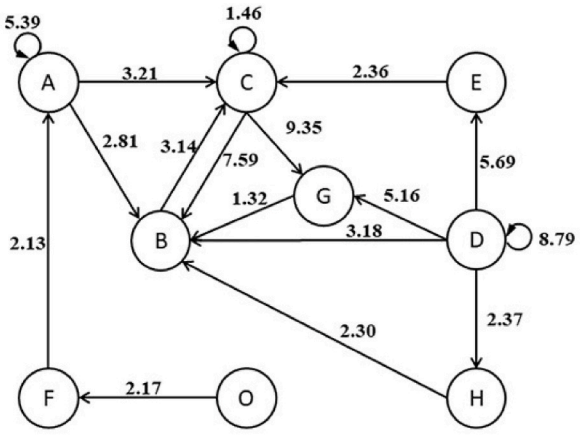


Fig. 8. Behavior patterns transition diagrams of the experimental group.

accessing AI ethical materials through exploring the application of AR models or AR scenes, and improves students' metacognitive awareness. In addition, students identified multiple areas for further inquiry in the AR learning materials. They then integrated different sources and content through resource searches, and presented views on writing answers for AI ethical tasks, which can improve their ability and creativity to solve complex problems.

On the other hand, the significant behavior patterns of the control group were revealed, as shown in Fig. 9. Unlike the experimental group, students in the control group had more social interaction unrelated to ethical content (O→O). Students with the conventional contextualized dilemma discussion approach had obstacles in entering the next AI ethical learning stage. It can be inferred that without AR guidance in the AI ethical dilemma discussion, students found it hard to enter the next learning stage, thus consequently lacking focus on the ethical problem-solving process.

6. Discussion and conclusions

Based on the empirical findings, the current study confirmed that the students' outcomes of AI ethics (i.e., learning achievement of AI ethical awareness with four sub-dimensions, AI ethical reasoning, and higher order thinking tendency) could be improved by the AR-based contextualized dilemma discussion approach in comparison with those who learned with the mobile learning system-guided contextualized dilemma discussion approach. Owing to the use of AR visualized interaction and AR guidance in linking the contextualized dilemma with AI ethics, the proposed approach in this study fostered students' AI ethical learning outcomes.

To address RQ1, this study examined the effectiveness of students' AI ethical learning awareness achievement in the AR-based AI ethics activity. We revealed that the students who learned with the AR-based contextualized dilemma discussion approach showed significantly higher learning achievements of AI ethical awareness than those who learned with the mobile learning system-guided contextualized dilemma discussion approach. This finding confirms the previous findings (AlNajdi, 2022; Chiang et al., 2014; Lin et al., 2022), which indicated that the use of AR could help students fully comprehend and deeply understand learning AI ethics conflict. This study integrates AR technology into the dilemma and enhances students' AI ethical learning outcomes (i.e., clear ethical principles related to internal AI ethics, reasonable examples and facts, and opposing views). If teachers hope to teach students to derive better solutions while facing AI ethical dilemmas and conflicts with opposing sides, they have to be able to not only obtain the AI ethical principles and concepts (i.e., ethical tendency) at the knowledge level but also to achieve the AI ethical competence to apply the learned knowledge to daily practice and action when encountering dilemmas. Therefore, the AR environment could become a favorable way to help students understand the contextualized dilemma complex phenomena in AI ethics by integrating the authentic context into the digital interactive learning content. The application of AR helps students become immersed in the ethical dilemma environment. This finding shares similarities with those of Salar et al. (2020) and Conley et al. (2020), who suggested using the AR immersion experience to influence students' attention focus. Furthermore, students can fully experience the dilemma of conflicts faced by the protagonists of the case and achieve a deep understanding of conflicts for further in-depth discussion. The AR-based contextualized dilemma discussion approach could be used to understand students' adoption of action in the right direction for social good discussed by different stakeholders.

For RQ2, this study theoretically elaborated and reflected on how the aforementioned approach fosters students' AI ethical reasoning due to the personalized AR guidance or assistance (i.e., the experimental group mechanisms of AR-based mobile system-guided contextualized environment for dilemma discussion to guide students to confront challenges by adopting what they had learned). This is in accordance with a previous study that emphasized the role of reasoning in enhancing ethical thinking competence (Schrier, 2017). However, Schrier (2017) only used role-playing video games and conventional media to present ethical scenarios for promoting students' reasoning, empathy, and reflection. This study extended the approach to promote students' AI ethical learning by combining reasoning into an AI ethics course using contextualized dilemma discussion and AR guidance. Furthermore, this study extended the findings of Burton et al. (2017), who indicated that teaching students how to reason for finding possible solutions is one of the crucial facets of learning AI ethics, by revealing the effect of the AR-based contextualized dilemma discussion approach on enhancing learners' AI ethical reasoning. Owing to the complex development of AI ethical competence, students may feel frustrated when encountering different problems in the dilemma discussion. The support of AR personalized guidance and instant feedback is needed to help students solve complex AI ethical learning difficulties in time. Accordingly, AR guidance provides potential opportunities for fostering students' AI ethical learning competence by applying the learned AI ethical principles in the long term to address AI ethical conflicts from the perspective of social good in daily life. Unlike the study of Borenstein and Howard (2021), which only highlighted the idea of incorporating reason and reflection into ethical courses for promoting AI ethics education, this study demonstrated the effectiveness of the proposed approach to enhance students' AI ethical reasoning with experimental study and behavior analysis. Specifically, the contextualized dilemma discussion of AI ethics with AR guidance would facilitate AI ethical learning from a surface to a deep level.

RQ3 examined higher order thinking tendency when students used the AR-based contextualized dilemma discussion approach. It was found that the students' higher order thinking tendency could be improved with the AR learning system-based contextualized dilemma discussion approach, thus responding to research question 3. This result was inconsistent with previous findings (e.g., Tawfik et al., 2020; Willems et al., 2021) regarding the most important factors in promoting students' higher order thinking tendency (e.g., creativity tendency and metacognitive awareness of complex problem solving). Specifically, although Willems et al. (2021) indicated the importance of authentic educational dilemmas for improving students' critical thinking and problem solving, they failed to reveal what behaviors are essential to improve the effect of contextualized dilemmas in an AR-supported AI ethics learning environment. Considering the need to inform the essential behaviors for learning AI ethics, we developed AI contextualized dilemma cooperation scenarios that supported students' in-depth discussion to facilitate team cooperation, communication, and complex problem solving. In

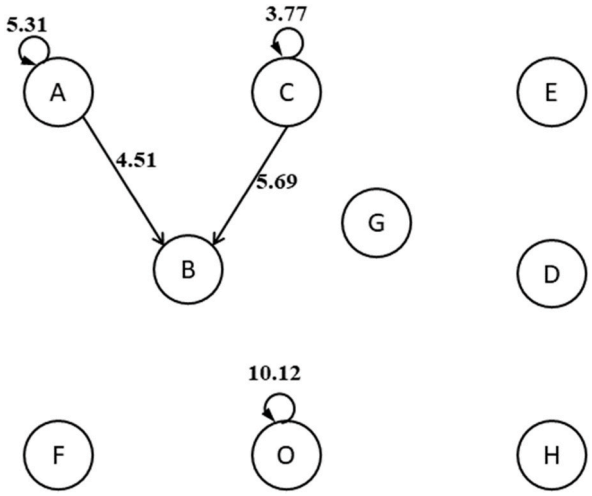


Fig. 9. Behavior patterns transition diagram of the control group.

addition, the role of contextualized dilemmas in the problem-based learning approach has been revealed to encourage students to discuss and solve problems in response to the related dilemma case (Tawfik et al., 2020). Nevertheless, Tawfik et al. (2020) did not clarify what approach is effective in terms of improving higher order thinking tendency. This study adds value to the previous study by identifying the effect of the combination of a contextualized dilemma discussion approach and AR learning guidance to cultivate students' higher order thinking tendency for more effective learning of AI ethics. Overall, the results provide empirical evidence for the effectiveness of the proposed approach in facilitating students' higher order thinking tendency in AI ethical learning.

RQ 4 inquired into what behavior is essential to ensure the effectiveness of the experimental group adopting the AR-based contextualized dilemma discussion approach, so the students' ethical behavior was analyzed. The LSA result explained a more sophisticated mechanism for AI ethical learning, which provides a deeper understanding and evidence of the effectiveness to help students transfer their AI ethical knowledge into their actions and values with the aforementioned approach. The uniqueness and effectiveness of the experimental group with the AR-based contextualized dilemma discussion approach for promoting students' sustainable behaviors of AI ethics have been revealed in this study. The sustainable behaviors of AI ethics with the proposed AR system consist of four main behaviors, that is, accessing AI ethical digital learning resources at the right time, identifying multi-area materials for further inquiry, adapting multiple types of information or reasoning from different views, and presenting views of AI ethics. Besides, they also inquired about further areas in the digital learning materials or integrated consistent views of different stakeholders to present their views in the proposed AR system. These findings are inconsistent with Chian et al. (2014). Although Chiang et al. (2014) study noted that the AR-enhanced inquiry-based guiding approach could promote students' participation, there is little evidence of which behaviors can effectively facilitate students' classroom participation. Contradicting Chiang et al. (2014), this study noted that students' repeated viewing of learning materials by AR could promote their classroom participation. These behaviors reflect that the AR-based contextualized dilemma discussion approach creates an immersive environment, overcomes the problem of effective dilemma preparation, induces students' thinking, and guides them to look at the problem from various perspectives. In addition, the students' ethical behavior indicated that with the support of AR guidance, they exhibited behavior patterns of solving complex problems and metacognitive awareness (i.e., higher order thinking tendency), which concurs well with the finding of Lin et al. (2022), indicating that higher order thinking tendency has the potential to improve AI ethics. Although the LSA analysis revealed potentially effective AI ethical leaning behavior patterns using the AR enhanced environment, the empirical results are to some extent limited by the learning environment. In other words, this study focused more on depicting the AI ethical learning process in the blended environment with the mobile and AR systems, rather than examining all their behaviors in the AI ethics learning processes (e.g., students' before-class behaviors in the real world were not collected in this study). This finding is, to some extent, in line with a previous study which noted that incorporating more subjective and objective measurements may have the potential to depict a clearer impact of using technology with instructional pedagogies in education (Wang et al., 2017). Future studies are encouraged to test the effect of the proposed approach without the constraints of the mobile learning system.

This study is one of the few which have examined the impact of the proposed approach on students' AI ethical outcomes within a two-week quasi-experiment. The two-week intervention in this study echoes the duration of interventions in previous research (e.g., Sari et al., 2021), which pointed out that a two-week AR-based behavior simulation could improve students' learning achievements of identifying moral conflicts by imagining themselves in a position to make decisions about ethical dilemmas using an experimental method. Additionally, unlike Tawfik et al. (2020), who emphasized that the role of contextualized dilemmas in a problem-based learning approach has been revealed to encourage students to discuss and solve problems in response to the related dilemma case, the current study indicated the importance of the AR visualized interaction and guidance to assist the contextualized dilemma discussion approach to help apply the learned knowledge to solve daily AI ethical dilemmas, which facilitate AI ethical learning from a surface level to a deep level. Surface ethical learning refers to learning processes that focus more on a single aspect of AI ethics (i.e.,

ethical tendencies or practices), which is limited to individual preventive AI ethical learning that cultivates students' basic AI ethical concepts and principles to enhance their awareness of anticipating and preventing possible problems. Deep ethical learning is described as an in-depth and spiritual AI ethical learning growth that influences students' reasoning, durability, and the effect of using AI with ethical principles in daily life. When supported by proper instructions, implicit motivation and unconsciousness at a deep level would inspire students to implement ethical principles for social good when facing ethical dilemmas (Steć et al., 2021). Previous studies have reported many methods for facilitating students' active engagement in ethical learning, for instance, the embedded ethical approach (Grosz et al., 2019), the project-based AI ethical learning approach (Williams et al., 2022), the inquiry-based pedagogical approach of using digital story writing (Ng et al., 2022), the ethical issues' context-real simulation with VR (Ramirez & LaBarge, 2020), and the philosophical reflective model (Demissie, 2015). The proposed approach in this study furthers the earlier research by combining the works of Demissie (2015), Grosz et al. (2019), Ng et al. (2022), and Williams et al. (2022). This study extends the existing pedagogy in ethical learning to promote both students' ethical tendency and ethical competence of AI ethics by integrating the AR-based contextualized dilemma discussion approach from a surface level to a deep level. Accordingly, to understand the AI ethical principles and risks, and to think deeply about how to solve complex AI ethical problems in real life, teachers could use AR visualized interactions to design embedded AI ethical contexts, semi-real AR simulations, inquiry-based discussion, and age-appropriate AI ethical role-play activities to promote students' active engagement in discussing AI ethical issues. Teachers should provide personalized AR guidance while encouraging students to apply the principles and concepts they have learned to situation-specific practice and action. This could then promote students' interaction and further practice (e.g., playing different roles to give reasonable examples to describe the AI ethical dilemmas). Overall, this study suggests three design guidelines for researchers or teachers who intend to apply the AR-based contextualized dilemma discussion approach to other AR-based ethical learning activities. (1) Encourage students to participate in experiencing dilemmas in immersive role-playing scenarios (e.g., the AR system helps students experience the autonomous driving dilemma with the first perspective to promote their ethical learning from surface to deep level when applying their learned AI knowledge to solve daily-life ethical problems); (2) Prepare a set of case-based visual discussions to apply the learned principles of AI ethics to daily problems in a semi-real situation under teachers' guidance and with system feedback; and (3) Select AR-enhanced activities combining virtual and real environments that require students to compare their existing misunderstandings of basic AI ethical concepts for surface ethical learning and inquiry into how to address contextualized dilemma problems for deep and spiritual AI ethical learning growth.

7. Implications and limitations

The theoretical contribution of this study is that it integrated AR with contextualized dilemma discussion on AI ethical teaching, and demonstrated its positive effect through a quasi-experiment. Experimental results showed that the proposed approach improved learning achievements of AI ethical awareness, ethical reasoning, and higher order thinking tendency. The current research is one of the pioneering studies to enrich the traditional dilemma discussion methods in AI ethics education by adopting the AR-based contextualized dilemma discussion approach. In terms of practical contribution, the proposed system reveals the following two crucial stages of AI ethical learning behaviors to add value to the traditional AI ethical learning practice, which lacks specific and detailed instructions. First, it is useful for teachers to embed non-intrusive AR guidance and AR visualized interactions into contextualized dilemma discussions to effectively encourage students' AI ethical behaviors. Second, to enhance higher order thinking tendency and ethical reasoning, it is necessary to train teachers in designing AR resources, authentic contextualized dilemmas, role-playing scenarios, and case-based visual stimulation.

On the other hand, the present study may have some limitations. First, the participants were Chinese sixth-graders. It might be improper to generalize the findings to other grades of students with different cultural backgrounds. Therefore, we will continue to carry out experiments and expand the scope of disciplines and research samples to make our findings more promotional. Second, it is essential to track the proposed approach for a longer period of time and conduct relevant experiments to clarify the influence of the approach on higher order thinking tendency, such as creativity and critical thinking, which are more difficult to acquire in AI ethical learning. Third, although both groups learned from the same learning content regarding AI ethical concepts and principles with the same resources provided by mobile devices, the subtle differences in the content structure of learning materials used by the experimental and control groups may have impacted the experimental results and behavior patterns. Accordingly, there is a need for future research to take this remaining influential factor and the fairness of the design of the two groups into consideration to make comparisons of their AI ethical learning outcomes and behavior patterns more reasonable.

Author contributions

Xiao-Fan Lin: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Resources. **Zhaoyang Wang:** Writing - Original Draft, Writing - Review & Editing. **Wei Zhou:** Methodology, Writing - Review & Editing. **Guoyu Luo:** Writing - Original Draft. **Gwo-Jen Hwang:** Writing - Original Draft, Writing - Review & Editing. **Yue Zhou:** Writing - Original Draft, Writing - Review & Editing. **Jing Wang:** Writing - Original Draft, Writing - Review & Editing. **Qintai Hu:** Writing - Original Draft, Writing - Review & Editing. **Wenyi Li:** Writing - Original Draft, Writing - Review & Editing. **Zhong-Mei Liang:** Resources, Writing - Original Draft, Writing - Review & Editing.

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Ethics declarations

This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Institutional Review Board (IRB) of the South China Normal University approved this study, SCNU-JXJ-2021-009.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article. All authors have confirmed that no partial financial support was received. There is no potential conflict of interest between the authors in this study.

Data availability

Data will be made available on request.

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