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Impacts of an augmented reality-based flipped learning guiding approach on students' scientific project performance and perceptions

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ABSTRACT

In recent years, flipped learning has received increasing emphasis; it engages students in deriving basic knowledge through instructional videos before the class, and hence more time is available for practicing, applying knowledge, or student-teacher interaction in class. Many scholars have pointed out that, with such a learning approach, teachers can design more effective in-class activities by guiding students to have higher order thinking as well as interactions with peers and teachers. In the meantime, researchers have also indicated that employing proper educational technologies or learning strategies could further improve students' performance. Therefore, in this study, an Augmented Reality (AR)-based learning guiding mode is proposed for developing a flipped learning system. To examine the effectiveness of the proposed approach, an experiment was conducted in a natural science learning activity of an elementary school using the developed system. The participants were four classes of 111 fifth graders. Two classes were assigned to the experimental group, while the others were the control group. Those learning in the experimental group used the AR-based flipped learning mode, while those in the control group learned with the conventional flipped learning mode. From the experimental results, it was found that the AR-based flipped learning guiding approach not only benefited the students in terms of promoting their project performance, but also improved their learning motivation, critical thinking tendency, and group self-efficacy.

1. Instruction

In traditional instruction, teachers spend most of the in-class time giving lectures; therefore, students rarely have chances to apply knowledge, practice, or interact with their peers and the teacher (King & Newmann, 2001). Several scholars have further pointed out the importance of fostering students' high-order thinking competences, such as problem-solving and critical-thinking abilities, which are vital in the 21st century (Arum & Roksa, 2011; Trilling & Fadel, 2009).

Owing to the advancements in computer and multimedia technologies, technology-enhanced learning has become an important trend in education. Researchers and school teachers have attempted to include technologies in educational settings to situate students in information-rich and interaction-promoting learning contexts. The flipped classroom is such a learning approach that engages students in a self-learning mode via browsing instructional videos before the class, such that more in-class activities can be conducted to facilitate peer interactions, practice, and student-teacher interaction (Stone, 2012). In recent years, many studies have reported the positive effects of the flipped classroom on students' learning outcomes in comparison with traditional instruction (Schultz, Duffield,

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Rasmussen, & Wageman, 2014). For instance, Hung (2015) applied the flipped classroom to a college English course and found that students' learning satisfaction was significantly higher than that in the traditional teaching mode.

On the other hand, several scholars have indicated that the effectiveness of the flipped classroom is due to not only the *flipping* of the in-class and out-of-class activities, but also the proper learning strategies adopted in the class. Well-designed in-class activities and effective learning management approaches are key to the success of flipped classrooms. For example, Strayer (2012) explored the differences between conventional instruction and the flipped classroom in a statistics course at a college. They found that, without appropriate teaching strategies or learning designs, students might feel frustrated when encountering problems in the flipped classroom. Hao and Lee (2016) also indicated the importance of applying proper teaching strategies and employing necessary measures in the flipped classroom to maintain students' learning motivation.

One of the aims of flipped learning highlighted by educators is the fostering of students' higher order thinking (Flumerfelt & Green, 2013). Researchers have emphasized the importance of developing learning activities to let students understand and solve complex problems based on the knowledge learned in school (Bergmann & Sams, 2014). Project-based learning is such a student-centered teaching mode, focusing on the content taught by the teachers, allowing students to explore and solve problems, and gaining knowledge and skills through the production process (Barab & Luehmann, 2002; Barak & Dori, 2004). On the other hand, it remains a challenging issue to provide individual students with guidance and instant feedback in a project-based activity conducted in the class since a teacher needs to face dozens of students at the same time.

Recently, the development of interactive technology has offered new opportunities for providing instant feedback and guidance in real-world learning scenarios. Scholars have indicated that different interactive technologies can be applied to different educational activities, depending on the features of the technologies and the objectives of the activities (Davies, Dean, & Ball, 2013; Koehler & Mishra, 2008). Among the emerging technologies, Augmented Reality (AR) has been recognized as a technology that can assist learners in dealing with real-world targets and tasks with supports from the digital systems (Chittaro & Ranon, 2007). Using AR in real-world learning activities could strengthen students' expression of spatial cognition, experiment operation ability, and collaborative learning (Choi & Baek, 2011; Dalgarno & Lee, 2010; Kye & Kim, 2008). Previous studies have also pointed out that if students can learn with technology facilitation during the learning process, not only can individual guidance be provided (Chen, Chang, & Wang, 2008), but students' learning effect can also be elevated (Chen & Huang, 2012).

Therefore, in this study, an AR-based flipped learning system approach is proposed to improve students' learning performance and critical thinking tendency as well as their learning motivation and group self-efficacy when conducting scientific projects in an elementary school natural science course. Therefore, based on the above research objectives, the following research questions are addressed in this study.

(1) In terms of learning achievement, do the students learning with the AR-based flipped learning system outperform those learning with the conventional flipped learning approach?
(2) In terms of learning motivation, do the students learning with the AR-based flipped learning system outperform those learning with the conventional flipped learning approach?
(3) In terms of critical thinking tendency, do the students learning with the AR-based flipped learning system outperform those learning with the conventional flipped learning approach?
(4) In terms of group self-efficacy, do the students learning with the AR-based flipped learning system outperform those learning with the conventional flipped learning approach?
(5) In terms of cognitive load, do the students learning with the AR-based flipped learning system have a lower cognitive load than those learning with the conventional flipped learning approach?

2. Literature review

2.1. Project-based learning (PBL)

Project-based learning originated in the early 20th century with the aim of inspiring students to learn actively (Kilpatrick, 1918). Project-based learning incorporates many features of constructivism, including requiring students to get actively involved in the project-based learning mode. Learning is a process of knowledge internalization. Learners can construct new thoughts and ideas based on their past knowledge, experience, and social environment. They can learn from each other or interact with the environment. Such an activity can boost cognitive skills, knowledge, and understanding. In other words, when students are arranged in a collaborative learning environment, they can discuss and exchange ideas through collaboration to come up with the answers to problems in their daily lives (Neo & Neo, 2009).

The design of project-based learning is to let students understand complex problems by investigation (Barron et al., 1998). Compared to inquiry-based activities, it requires more collaboration and coordination among group members, and the interaction can improve their learning outcomes. Project-based learning is considered an important learning strategy because students can benefit by completing learning tasks, having chances to produce, learn, and assess (Laffey, Tupper, Musser, & Wedman, 1998; Nagel, 1996). They are also encouraged to learn how to solve problems in real life. Furthermore, project-based learning combines the course, teaching methods, and assessment into one single learning activity.

The design of project-based learning emphasizes the content teachers teach, and students can explore and solve problems with their peers. Students can gain the knowledge, skills, and learning content through the process of production. Project-based learning has been proved to be an effective teaching and learning strategy (Huang, Shen, & Mak, 2002; Marchaim, 2001; Murphy & Gazi-

Demirci, 2001) and has become popular. The main reason is that it corresponds to the learning concepts of constructivism, cognitive psychology, and interdisciplinary courses. The literature has indicated that PBL helps students to become interactive learners (Blumenfeld et al., 1991; Lin & Hsieh, 2001) and to construct knowledge through exploration (Edward, 1995; Jang, 2006; Johnson & Aragon, 2003; Prince & Felder, 2007).

Many scholars have attempted to include PBL in courses to increase students' interaction and chances to practice. Chang and Lee (2010) included the collaboration mechanism in PBL in a vocational high school computer skills training course; it was found that the students benefited in terms of communication, organization, and skills practice. Meanwhile, Heo, Lim, and Kim (2010) applied PBL in online collaborative learning. There were 17 junior high school students in this learning activity. They were divided into groups and engaged in online discussion to finish the project assigned in the course. It was found that the students' involvement, communication skills, and team spirit improved in the PBL activity. Furthermore, Ardaiz-Villanueva, Nicuesa-Chacón, Brene-Artazcoz, de Acedo Lizarraga, and de Acedo Baquedano (2011) used PBL with third-grade students in a software engineering academy to help them develop creativity and knowledge and finish projects within 15 weeks. It was found that such an activity helped the students develop, assess, and select possible approaches to complete the project, and it created a positive and aggressive atmosphere. Besides, the students' creativity and academic performance both increased.

On the other hand, teachers have also pointed out that during the process of using PBL, some problematic situations might occur. First, teachers could have difficulties accessing the unfamiliar devices or environments; second, compared to practicing instruction, the content of basic courses changes constantly; third, teachers lack real educational experience; and fourth, new course content needs to be included in the complex course management (Zhou, Wu, Wu, Shen, & Zhou, 2015). These are all reasons why teachers may not be able to change their course teaching methods.

However, researchers have pointed out some problems in the previous research. The difficulties of using PBL in large classrooms include the promotion of students' learning motivation, students' focus on the learning tasks, linking the new with the old knowledge, and having more effective collaborative learning (Blumenfeld et al., 1991; Gulbahar & Tinmaz, 2006; Lee & Tsai, 2004; Marx, Blumenfeld, Krajcik, & Soloway, 1997). Besides, providing students with a method to organize their knowledge is also important. Therefore, developing an effective PBL activity has become an important and challenging issue (Woods, 2000).

2.2. Flipped classroom and flipped learning

The term *flipped classroom* refers to an instructional approach that delivers learning content, usually in the form of online videos, before class. The objective of a flipped classroom is to have more class time to engage students in practice and in peer interactions with the assistance and guidance of the teacher rather than practicing without assistance at home (Bergmann & Sams, 2012a; Hao, 2016). Researchers have provided several suggestions for effectively implementing flipped classrooms, such as developing instructional videos based on the cognitive theory of multimedia learning, engaging students in online discussion and completing learning sheets after reading the instructional videos, designing in-class practice tasks with suitable challenges, and evaluating individual students' learning performances and providing assistance accordingly (Hwang, Lai, & Wang, 2015; Lo, 2018).

In the past decade, many applications of the flipped classroom have been reported to show its benefits in terms of improving students' learning performance (Bergmann & Sams, 2012b; Hao & Lee, 2016; Tucker, 2012; Warter-Perez & Dong, 2012). For example, Davies et al. (2013) used the flipped classroom approach in an information systems spreadsheet course and found that the students focused more on the practice and had promising learning performance. Roach (2014) implemented a flipped classroom in a college economics course and found that the approach could facilitate peer interactions in the class.

Bergmann and Sams (2014) further believed that a flipped classroom is just a basic pattern of the flipped learning mode. They indicated that flipped learning is a student-centered learning mode with diverse learning designs, such as problem-based learning, project-based learning, and individualized learning. Implementing the concept of flipped learning can engage students in higher order thinking through the use of learning strategies before and in the class. Accordingly, several attempts have been made to conduct flipped learning to engage students in higher order thinking. For example, Saulnier (2015) used the flipped learning mode in a system analysis and design course to increase students' participation and learning outcomes, and Kong (2014) used the flipped learning mode in a social science course to cultivate students' information literacy and critical thinking ability.

From most of the studies mentioned above, it has been found that, compared to the traditional teaching mode, the flipped classroom or flipped learning has good potential for improving students' learning performance as well as promoting their positive attitudes toward learning actively at home via the instructional videos and participating in the in-class activities. On the other hand, researchers have indicated the challenges of conducting flipped learning; for example, students might feel anxious and frustrated when learning on their own before the class and dealing with complex tasks in the class (Strayer, 2012). Consequently, it is necessary to incorporate effective learning strategies or tools into the flipped learning (Hwang & Lai, 2017; Saulnier, 2015).

2.3. Augmented reality (AR)

Azuma (1997) indicated three main elements of AR, namely virtual objects combined with real objects, simultaneous interactive information, and 3D presentation. In other words, AR can provide users with interaction between the real environment and virtual objects, and increase their engagement while using it (Chang et al., 2014). Azuma (1997) believed that combining virtual and real environments to have in-time interaction can bring users a sense of engagement and immersion in the scenarios. Pence (2010) mentioned that there are two identification methods of AR, marker-based AR and marker-less AR. The former means that users need to use mobile devices to scan the marked AR-code to gain the virtual information, while the latter means that the mobile devices would provide corresponding virtual information based on users' locations via the GPS function of the mobile devices.

With the advancements in the technology and recognition skills, AR can now be presented through vision recognition. Cheng and Tsai (2012) further divided AR into location-based AR and image-based AR. The former means that, through the GPS function of mobile devices, users' location can be known, and virtual information is provided based on their location. Using this feature to conduct mobile learning, students would not be limited by location, and can observe the surrounding objects more directly. On the other hand, the latter includes picture recognition and actual image recognition.

Sommerauer and Müller (2014) used AR in a tour of a mathematics exhibition; through visual recognition, users could watch the animation of the exhibits and retain knowledge of mathematics and the concepts of the exhibits; the results showed that users gave positive feedback on this way of touring, and it offered them a better way to understand the exhibits. Regarding the aspect of designing courses, Wei, Weng, Liu, and Wang (2015) applied AR software in a creative design course, and students' learning motivation, learning results, and creativity were investigated; the results showed that this way can increase students' learning motivation, creativity, and learning results. In a physics course, Ibáñez, Di Serio, Villarán, and Kloos (2014) proposed AR for teaching electromagnetism, and investigated the students' flow, usage experience, and system usefulness; the results showed that the students using the AR system had higher flow than those using the conventional teaching method.

From the above visual recognition type of AR studies, it was indicated that students learning with AR outperformed those learning with conventional teaching methods in their learning results. The visual recognition type of AR can recognize 2D pictures in textbooks or read AR-Code to present the abstract content or virtual information that textbooks or teaching materials cannot present, such as the collision effects in physics or changes in magnetic force. It allows students to interact with the virtual objects or information instead of having to use their imagination or make hypotheses.

Regarding location-based AR, Chang, Hou, Pan, Sung, and Chang (2015) used AR combined with interview strategies to conduct a touring activity for locating historic information. A total of 87 college students were divided into three groups to experience tour learning in order to increase their learning results and a sense of localization.

Scholars have also implemented AR on field trips in natural science courses (Kamarainen et al., 2013). Chiang, Yang, and Hwang (2014) combined AR with inquiry-based mobile learning, and developed a location-based AR inquiry mobile learning system in natural science courses to let students learn about aquatic plants; the results showed that the students using the location-based AR inquiry mobile learning system learned repeatedly and raised new questions; besides, the students using this system could read the information on their mobile devices, allowing them to gain supplementary information more effectively and to share it with their classmates.

The above examples of the implementation of AR in education research indicate that AR can effectively increase students' learning motivation and learning results; hence, students' interaction and collaboration with peers can be improved. In addition, several researchers have indicated that the use of AR in school settings has good potential for improving learners' motivation (Cheng, 2017), critical thinking (Chao, Chang, Lan, & Sung, 2016), cognitive load (Cheng, 2017; Hsu, 2017), and self-efficacy (Lin & Chen, 2015). Therefore, this study attempts to measure students' learning motivation, critical thinking, cognitive load, and self-efficacy in an activity, in which image-based AR was adopted to guide students to conduct electromagnetic experiments.

3. An augmented reality-based flipped learning guiding approach

In this study, flipped classroom teaching activities and an AR-based flipped learning system were developed, as shown in Fig. 1. Unity, a 3D game-development tool published by Unity Technologies, was employed to develop the AR system. Fig. 1 shows the

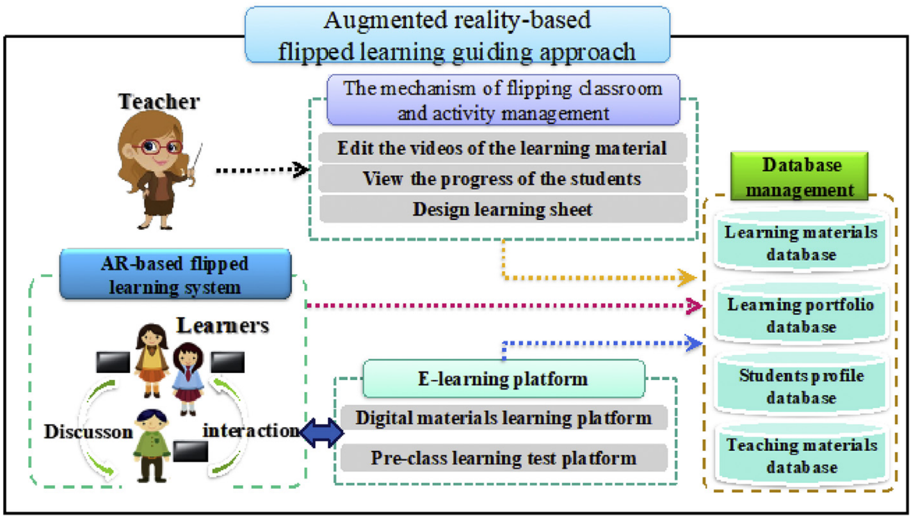

Fig. 1. The structure of the augmented reality flipped learning system.

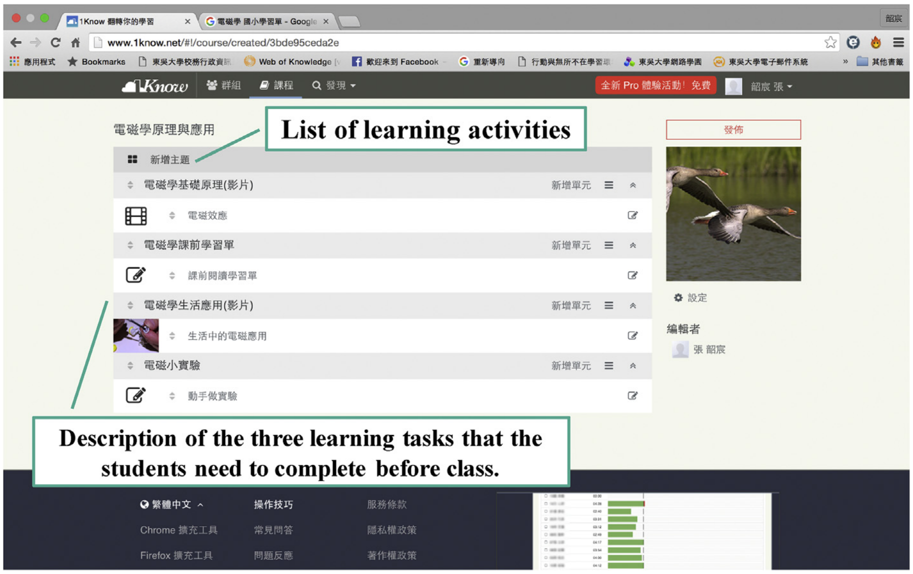

Fig. 2. A description of the learning process and activity list.

structure of this study, which consists of an AR-based flipped learning system, a flipped classroom and activity management system, an e-learning platform, and a server database management mechanism; moreover, the AR-based flipped learning system contains several databases, including a learning materials database, student portfolio database, learning portfolio database, and teaching materials database. The learning materials database is used to store the supplementary materials, learning sheets, and guiding instructions. The student portfolio database and the learning portfolio database is used to store students' personal information and learning records, respectively. Moreover, the teaching materials database is designed for storing the instructional videos provided by teachers.

In this study, the learning content is based on the concept of *electromagnetism*, which is included in the elementary natural and living technology course. Students need to log into the flipped learning system to study the pre-class learning content. They can follow the learning list to finish the flipped learning activities, as seen in Fig. 2.

The learning platform provides instructional videos for the students to learn the "Electromagnetism Principle" unit content before the class. The students could repeatedly watch the videos and make annotations to raise questions and discuss with peers and the teacher later in the class, as shown in Fig. 3.

After they finished the learning content, the students had to complete the worksheet, the content of which was an extension of the video content. For example, they might be asked to give examples of electromagnet applications in their life, as shown in Fig. 4.

After the student completes the pre-class study, the teacher will explain the functions of AR, and the system will then guide the

Fig. 3. Interface of watching the videos and taking annotations.

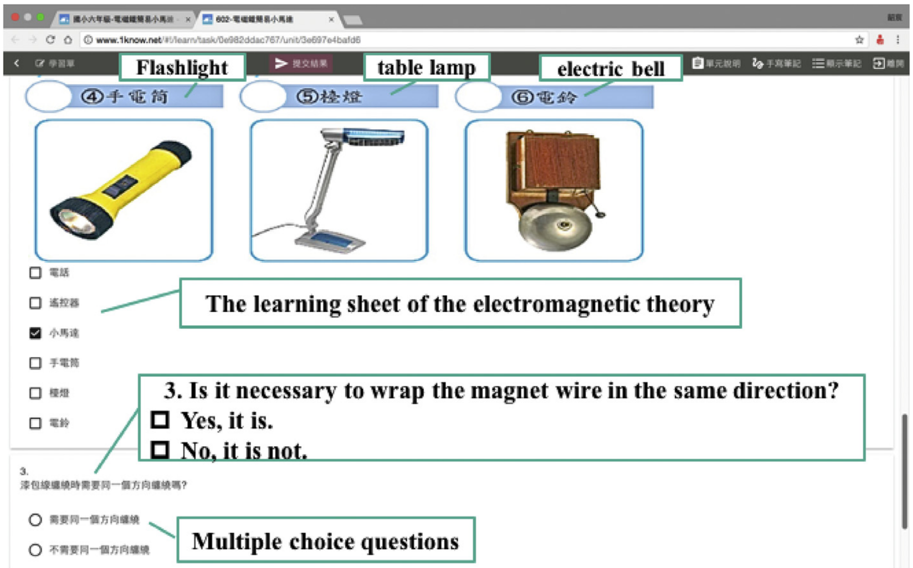

Fig. 4. The worksheet learning content.

students to begin the electromagnetic experiment operation. At first, the system will guide the students to prepare experimental equipment and props, and the operation instruction animation will appear on the flat screen to guide them to know how to operate the experimental props, as shown in Fig. 5.

If the students make errors in the steps of the operation process or if they place the props in the wrong position, the system will take the initiative to remind or inform them, so that they can quickly enter the learning situation. The system guides the students according to their individual progress in the experimental steps, until they complete the experimental procedure. If the students want to re-test the operation again in the operation process, they can choose the part that they want to practice again. The AR operation system provides them with opportunities to re-practice, as shown in Fig. 6.

The AR operating guidance system will not only join the animation guide, but will also provide the students with the magnetic field of magnetic force and magnetic flow direction. The students can therefore understand the operation of the magnetic interaction with the flow direction, and can truly understand the magnetic interaction principle as shown in Fig. 7.

4. Experiment design

To evaluate the effectiveness of the AR-based flipped learning system, an experiment was conducted on an elementary school science class to compare the students' learning achievements, critical thinking, group self-efficacy, learning motivation, and mental load. The selected subject unit was the "magnetic force" unit of an elementary school natural science course. The aim of the subject unit was to foster students' ability of electromagnetic effect and electromagnet applications.

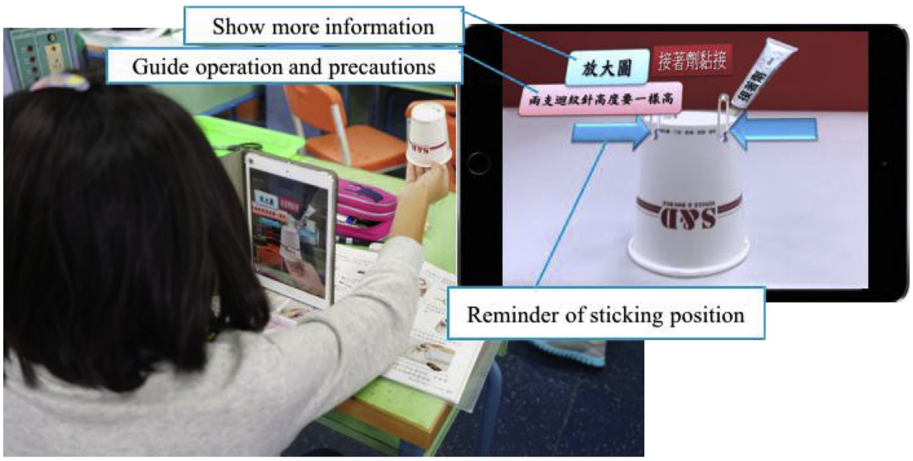

Fig. 5. The interface of the augmented reality operating guidance animation.

Fig. 6. Prompts for incorrect operation of the augmented reality system.

Fig. 7. The augmented reality prompt animation of magnetic field lines.

4.1. Participants

The participants of the experiment were 111 fifth graders from four classes. Two classes with 56 students were randomly assigned to the experimental group, in which they were guided by the AR-based flipped learning system. The other two classes of 55 students were the control group, who learned with the conventional flipped learning approach. The students in both the experimental group and the control group were randomly assigned to small teams of two to three students. The team members were allowed to determine their roles and work in the project. In order to avoid the influence of different instructors on the experimental results, all of the students were taught by the same instructor who had taught the natural science course for nearly 10 years.

4.2. Experimental process

Fig. 8 shows the procedure of the 6-week experiment. At the beginning of the experiment, the students were asked to complete a small science project regarding the implementation of an electromagnet to evaluate their implementation competence before the learning activity. They also took a pre-test to evaluate their basic knowledge of the electromagnetic effect. Following that, the students completed the pre-questionnaires of learning motivation, critical thinking tendency, and group self-efficacy.

During the learning activity, all of the students participated in the flipped classroom. They had to watch the pre-class videos and

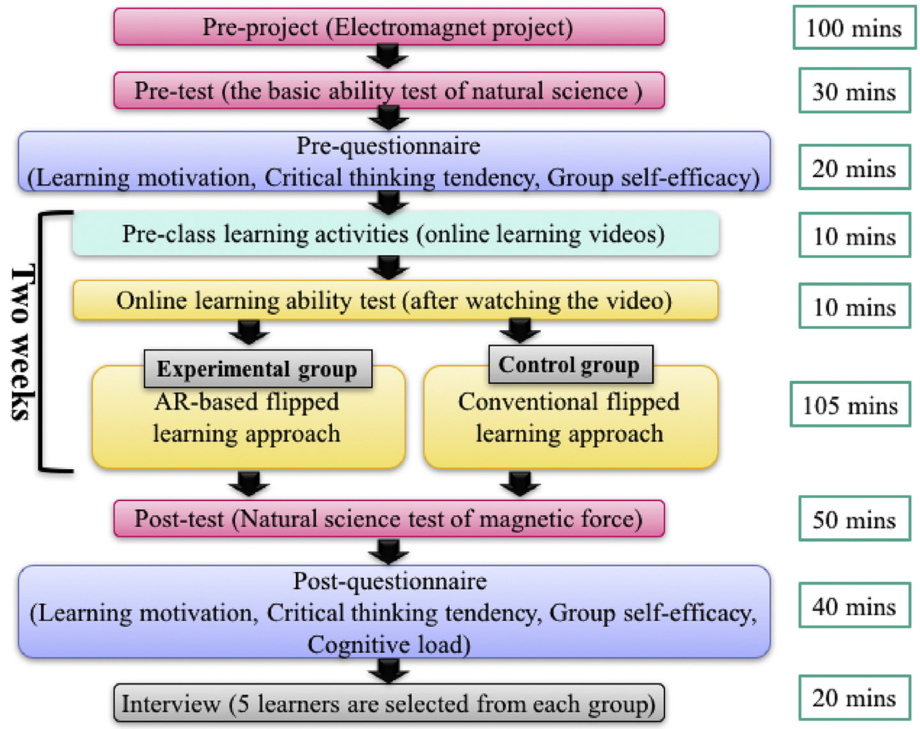

Fig. 8. Experimental design of the learning activities.

finish the worksheets at home. Therefore, the students in the experimental group learned with the AR operating guidance system and discussions in class. On the other hand, those students in the control group were guided by the teacher to finish the science project, worksheet and have discussions in the class. The time for the students to complete their learning task, that is, to develop an electromagnet motor, was totally 210 min in 2 weeks. Both groups used the same learning content in the flipping learning activities, including the pictures and videos. In addition, the learning content taught by the teacher was the same as the content in the AR guiding system.

After the learning activity, the students took the post-test and completed the post-questionnaires of critical thinking, group self-efficacy, learning motivation, and mental load. Finally, five learners were selected from each group to take part in an interview.

4.3. Measuring tools

The research tools of this study included the questionnaires for measuring the students' "learning motivation," "critical thinking," "group self-efficacy," and the questionnaire for surveying the cognitive load of the two groups who used the different approaches.

Both the pre-test and the post-test of science knowledge were designed by two experienced natural science teachers. The pre-test aimed to evaluate the students' prior knowledge of the natural science course content. It consisted of 20 multiple-choice items, such as "Which household goods are made using the electromagnetic principle?" The post-test included 10 multiple-choice items (50%), two matching items (20%), one fill-in-the-blank item (10%), and two short-answer questions (10%) for assessing the students' knowledge of the electromagnetic effect and electromagnet applications. The perfect score of the post-test was 100. Its Cronbach's alpha value was 0.72, showing acceptable reliability in internal consistency.

The first project conducted before the activity was related to the implementation of an electromagnetic. The students needed to use knowledge related to the physical interaction between charged particles to make an electromagnet work. Moreover, they were asked to complete another project as the post-test of the project at the end of the experiment. Both projects were scored by two experienced teachers who had taught the natural science course for nearly 10 years. The scoring criteria consisted of four dimensions: accuracy, completeness, sophistication, and durability. The perfect score was 100, as shown in Table 1.

The learning motivation questionnaire was modified from that developed by Keller (2010), and had six items in this study. A 5-point Likert rating scheme was employed in this questionnaire, where 1 represented *highly agree* and 5 represented *highly disagree*. The Cronbach's alpha value of the questionnaire was 0.90.

The questionnaire of critical thinking tendency was modified from the measure developed by Chai, Deng, Tsai, Koh, and Tsai (2015). It consisted of six items (e.g., "I will think about whether what I have learned in this learning activity is correct or not" and "In this learning activity, I will try to understand the new knowledge from a different point of view") with a 5-point rating scheme. The Cronbach's alpha value of the questionnaire was 0.71, showing good reliability in internal consistency.

The group self-efficacy questionnaire consists of seven items using a 5-point Likert scale ranging from 1 to 5. It was modified from

Table 1
The rubrics for scoring the project.

Dimensions	Scale				
	5 points	10 points	15 points	20 points	25 points
Accuracy	Enameled wire was wound less than 10 times and there was enameled wire irregularity.	Enameled wire was wound less than 15 times and there was a little enameled wire irregularity.	Enameled wire was wound less than 20 times and there was a little enameled wire regularity.	Enameled wire was wound 20 times and there was enameled wire regularity.	Enameled wire was wound more than 20 times and the enameled wire was very regular.
Completeness	Less than 60% complete.	Less than 70% complete.	Less than 80% complete.	Less than 90% complete.	100% complete.
Sophistication	Fixed adhesion point is dirty and the enameled wire is very messy.	Fixed adhesion point is a little dirty and the enameled wire is slightly messy.	Fixed adhesive point is quite clean and the enameled wire is quite neat.	Fixed adhesive point is clean and the enameled wire is neat.	Fixed adhesion point is very clean and the enameled wire is very neat.
Durability	The small motor continues to rotate less than 5 turns.	The small motor continues to rotate less than 10 turns.	The small motor continues to rotate less than 15 turns.	The small motor continues to rotate less than 20 turns.	The small motor continues to rotate more than 20 turns.

the questionnaire developed by Wang and Lin (2007) for measuring the students' group self-efficacy in teaching the subject unit, that is, their expectations and confidence regarding learning the architecture design course well. The Cronbach's alpha value of the questionnaire was .82, implying that the questionnaire is reliable.

The questionnaire of cognitive load was modified from the measure developed by Hwang, Yang, and Wang (2013). It consists of eight items in two dimensions; that is, five items for "Mental Load" (e.g., "The learning content in this activity is difficult for me") and three items for "Mental Efforts" (e.g., "I think I need to spend a lot of effort to organize the information of the learning activities"). The Cronbach's alpha values of the questionnaire and the two dimensions were 0.97 and 0.88, respectively.

The interview questions in this study were modified from the measure developed by Hwang, Yang, Tsai, and Yang (2009). It consists of seven questions to collect students' perceptions of the learning activity. The interview content was recorded as audio files for analysis. Examples of the interview questions include: "What is the advantage of this learning approach that benefits you the most? Why do you think so? Please give an example" and "What's the difference between the experience in this learning activity and your previous learning experience?".

5. Experimental results

After the experiment, ANCOVA (Analysis of Covariance) was used to examine the students' natural science learning achievements and their perceptions of the learning activity from different dimensions by excluding the impacts of the pre-test scores and pre-questionnaire ratings, respectively.

5.1. Analysis of learning achievements of knowledge test

Before conducting ANCOVA to analyze the students' learning achievements, the homogeneity of the regression coefficient was tested on the two groups' pre-test scores and was confirmed with $F = 1.26$ ($p > 0.05$), revealing that ANCOVA could be used to analyze the post-test scores of the two groups.

As shown in Table 2, the adjusted mean value and standard error of the post-test scores were 84.53 and 1.10 for the control group and 86.98 and 1.10 for the experimental group. According to the results ($F = 2.49$, $p > 0.05$), no significant difference was found between the knowledge test scores of the two groups; that is, the AR operating guidance system did not benefit the students more than the conventional approach in terms of gaining knowledge in the flipped classroom.

5.2. Analysis of the project performance

Before conducting ANCOVA to analyze the students' project performance, the homogeneity of the regression coefficient was tested on the two groups' first-project scores and was confirmed with $F = 0.70$ ($p > 0.05$), revealing that ANCOVA could be used to analyze the second-project scores of the two groups.

As shown in Table 3, the adjusted mean value and standard error of the second-project scores were 85.08 and 1.10 for the control group and 93.97 and 1.09 for the experimental group. According to the results ($F = 33.21$, $p < 0.001$), there was a significant difference between the two groups; that is, the students who learned with the AR operating guidance system with the flipped classroom learning approach showed significantly better project performance than those who learned with the conventional flipped classroom learning approach. Furthermore, the value of η^2 was 0.43, representing a moderate effect size (Cohen, 1988).

5.3. Learning motivation for science

In terms of learning motivation, before conducting ANCOVA to analyze the students' learning motivation, the homogeneity of the regression coefficient was tested on the two groups' learning motivation ratings and was confirmed with $F = 0.01$ ($p > 0.05$), revealing that ANCOVA could be used to analyze the learning motivation ratings of the two groups.

Table 4 shows that the adjusted mean value and standard error of learning motivation ratings were 2.56 and 0.89 for the control group and 4.10 and 0.88 for the experimental group. According to the results ($F = 139.00$, $p < 0.001$), there was a significant difference between the two groups. That is, the AR operating guidance system with the flipped classroom learning approach had significant impacts on improving the students' learning motivation. The value of η^2 was 0.56, representing a moderate effect size.

5.4. Analysis of critical thinking tendency

The mean values and standard deviations of the pre-test scores were 3.91 and 0.61 for the control group, and 3.36 and 0.35 for the

Table 2
The ANCOVA result of learning achievement.

Group	N	Mean	SD	Adjusted Mean	SE	*F*
Experimental Group	56	86.89	8.84	86.98	1.095	2.489
Control group	55	84.62	10.1	84.53	1.101	

Table 3
The ANCOVA result of the students' project performance.

Group	N	Mean	SD	Adjusted Mean	SE	*F*	η^2
Experimental Group	56	93.95	5.616	93.97	1.085	33.21***	0.42
Control group	55	85.10	9.998	85.08	1.095		

***$p < 0.001$.

Table 4
The ANCOVA result of students' learning motivation.

Group	N	Mean	SD	Adjusted Mean	SE	*F*	η^2
Experimental Group	56	4.04	0.66	4.10	0.88	139.00***	0.56
Control group	55	2.63	0.61	2.56	0.89		

***$p < 0.001$.

experimental group. After verifying that the assumption of homogeneity of regression was not violated with $F = 0.401$ ($p = 0.528 > 0.05$), it was evident that ANCOVA could be applied to the analysis of the two groups' critical thinking ratings.

As shown in Table 5, the analysis of covariance (ANCOVA) was used to test the difference between the two groups by using the pre-test scores as the covariate and the post-test scores as dependent variables to decrease the interference of the pre-test scores on the experimental results. The adjusted mean value and standard error of the post-test scores were 2.59 and 0.11 for the control group, and 4.13 and 0.10 for the experimental group. According to the results ($F = 95.66$, $p < 0.001$), there was a significant difference between the two groups; that is, the students who learned with the AR operating guidance system with the flipped classroom learning approach showed significantly better learning achievements than those who learned with the conventional flipped classroom learning approach. The value ofη^2 was 0.49, indicating a moderate effect size.

5.5. Analysis of group self-efficacy

In terms of learning motivation, before conducting ANCOVA to analyze the students' group self-efficacy, the homogeneity of the regression coefficient was tested on the two groups' group self-efficacy ratings and was confirmed with $F = 0.40$ ($p > 0.05$), revealing that ANCOVA could be used to analyze the group self-efficacy ratings of the two groups.

Consequently, the analysis of covariance (ANCOVA) was used to test the difference between the two groups by using the pre-questionnaire scores as the covariate and the post-questionnaire scores as dependent variables to decrease the interference of the pre-test scores on the experimental results. As shown in Table 6, the adjusted mean value and standard error of the post-questionnaire scores were 2.24 and 0.85 for the control group, and 4.17 and 0.84 for the experimental group, as shown in Table 6. According to the results ($F = 57.75$, $p < 0.001$), there was a significant difference between the two groups. That is, the AR operating guidance system with the flipped classroom learning approach was able to significantly improve the students' group self-efficacy. The value of η^2 was 0.46, indicating a moderate effect size.

5.6. Analysis of cognitive load

To compare the cognitive load of the students who learned with the AR operating guidance system with the flipped classroom learning approach and the conventional flipped classroom learning approach, a *t*-test was employed to test the difference between the two groups. As shown in Table 7, the mean values of the post-questionnaire scores were 2.36 for both the control group and the experimental group, so there was no significant difference between the two groups.

5.7. Interview results

The interviews were conducted in the form of focus groups for a 20-min interview. One focus group involving 5 students from the experimental group and another involving 5 students from the control group.

By analyzing the students' feedback, it was found that the experimental group students generally held three points of view

Table 5
The ANCOVA result of students' critical thinking tendency.

Group	N	Mean	SD	Adjusted Mean	SE	*F*	η^2
Experimental Group	56	4.04	0.75	4.13	0.1	95.66***	0.49
Control group	55	2.65	0.71	2.59	0.11		

***$p < 0.001$.

Table 6
The ANCOVA result of group self-efficacy.

Group	N	Mean	SD	Adjusted Mean	SE	F	η^2
Experimental Group	56	4.12	0.71	4.17	0.84	57.75***	0.46
Control group	55	3.30	0.57	2.24	0.85		

***$p < 0.001$.

Table 7
The ANCOVA result of cognitive load.

Group	N	Mean	SD	t
Experimental Group	52	2.36	1.21	−0.09
Control group	53	2.36	1.09	

regarding the use of the AR operating guidance approach in flipped learning, that is, they could "practice at their own pace," it provided "personalized guidance for the operation," and it "increased the interest of the activity." For example, A10 stated that "A lot of steps I did not know how to do when the teacher taught us in the class. But the augmented reality operating guidance approach can let me repeat the operation again." A07 stated that "The augmented reality system is interesting and smart. It knows my current progress rate and provides the hints and instructions that I need." Therefore, the experimental group students, through the guidance of the AR system, could learn in accordance with their own rate of progress. At the same time, they could find the necessary steps and tips to help them complete the electromagnetic motor in the learning process.

On the other hand, the control group students focused on the advantages of the flipped classroom during the interview. A number of students stated that it was helpful to replace the part of the teacher who taught the memory-based knowledge with the instructional videos in the flipped classroom so that the teacher had more time in class to explain the projects in more detail; moreover, the students were allowed to ask questions in class, helping them keep up with the progress of the activities.

6. Discussion and conclusions

In this study, an AR-based flipped learning system approach was proposed. From the experimental results, it was found that, with the help of the AR guiding mechanism, the students' learning achievements (i.e., the project performance), learning motivation, critical thinking tendency, and group self-efficacy were significantly improved.

Regarding knowledge testing, to further investigate the reason why no significance was found in the learning results of the students learning with the proposed mode and the conventional flipped classroom, the students' interview records were analyzed. It was indicated that the students using the AR-based flipped learning system expressed that there was no content for practice in the system; the time for the experiment was too short so they could not remember the content that had just been taught. From this, it can be known that the learning content focused on the skills for operation procedures and there was very little "remembering" type of knowledge when students were using AR to learn; therefore, the experiment did not help students review the knowledge that had just been gained.

Moreover, from the project performance analysis, it was found that those learning with the AR-based flipped learning approach showed significantly better project performance than those learning with conventional flipped learning. To further investigate the reason why significance was found between the proposed mode and the conventional flipped learning, the student interview records were analyzed. It was found that, in the flipped classroom, although the teacher had more time to explain the learning tasks in detail, the students still encountered difficulties in the electromagnetic motor production process. Because the problems encountered by the students might not be the same, the provision of personalized assistance or guidance is needed. The experimental results showed that the use of AR technology is an effective approach to cope with this problem.

Both the experimental results and the results of the student interviews confirm the conceptions proposed by several researchers that, via provisioning AR components (text, animations, images, etc.) from the learning system during the learning process, students are able to learn course content and complete learning tasks in a more effective way (Cai, Wang, & Chiang, 2014; Chen & Tsai, 2012; Wu, Lee, Chang, & Liang, 2013) as well as improving their practice skills (Akçayır, Akçayır, Pektaş, & Ocak, 2016). Many researchers have also reported that increased interaction positively affects students' learning outcomes (Fulantelli, Taibi, & Arrigo, 2015). Therefore, the AR operating guidance system with the flipped classroom learning approach is able to encourage students to interact and practice more.

However, there are still some limitations to this study. First, the image-based AR can be affected by lights and angles, so recognition failure might occur during the process inside the classroom. Therefore, it is suggested that if researchers want to use image-based AR, the above problems should be conquered to lower any factor affecting the inference of the experimental results. Furthermore, although collaboration is a factor that might affect students' learning outcomes in project-based learning, it was not taken into account in the present study. In the future, we plan to apply the approach to other course content by taking more factors (e.g., collaboration and personal features) into account. Moreover, it is expected that other learning strategies can be considered in the flipped classroom, and the effects of applying those strategies on students' performances and perceptions can be further analyzed and compared.

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