Effects of learning physics using Augmented Reality on students’ self-efficacy and conceptions of learning

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Abstract
The Augmented Reality (AR)-based learning environment not only provides educators with novel ways to present learning materials but also give learners the opportunity to spontaneously interact with the material. Previous studies have shown that AR has many advantages in education; however, few focuses on the mechanisms behind promoting inquiry motivation, such as the effect of AR on learners’ self-efficacy and conceptions of learning. This study developed an AR-based wave-particle duality learning application, “AROSE,” to explore the effect of AR technology on students’ self-efficacy and conceptions of learning physics. A quasi-experimental study method was used, and 98 high school students aged between 16 and 18 were randomly assigned to experimental and control group. After a 4-week intervention, it was found that integrating AR technology into physics classrooms can (1) significantly enhance students’ physics learning self-efficacy, as indicated by understanding of concepts, higher-level cognitive skills, practice and communication; (2) guide students to be more inclined to higher-level conceptions of learning physics rather than lower ones; and (3) stimulates students’ motivation to learn more deeply.

Introduction
Physics education is currently morphing from simple exchange of knowledge, given and received in lectures with students’ imitation of experimental operation to creating an environment for students to actively participate in scientific inquiry process and independently acquire knowledge. Under a pedagogical context, optics is one of the more challenging topics in routine instruction. Some factors could be that there are concepts in the optics that are too abstract for students to understand (Galili & Hazan, 2000; Mcdermott & Redish, 1999); Moreover, when introducing optics, teachers normally will conduct many in-class demonstrations on optical properties, the majority of which require complicated lab tools and equipments that are often difficult to be used in classroom for myriad of practical reasons.
Practitioner Notes
What is already known about this topic
- The AR-based learning environment provides educators novel ways to present learning material.
- The AR-based learning environment give learners opportunity to naturally interact with the material.
- Most AR studies concentrating in physics focused on the role of AR technology in “improving academic performance” and “enhancing learning motivation,” but few of them studied the mechanisms behind them.

What this paper adds
- AR-based learning environments can motivate students to learn more deeply.
- AR technology has a significant positive effect on strengthening student self-efficacy, promoting higher-level conceptions and decreasing lower-level conceptions.
- AR has a comparative advantage to learning via Flash, another form of educational technology in classroom teaching & learning.

Implications for practice and/or policy
- Integration of AR into education can be of any grade band and virtually subject in traditional school settings; it strengthens pedagogy by incorporating technology.
- AR is a tool that explains material well by visualization and overcoming realistic barriers.
- AR is best done under an inquiry classroom or lesson setting, in which students should be encouraged to explore the given content in teams.

However, computer software and virtual experiment environments can provide educators and students new opportunities of inquiry-based learning and teaching. Emerging technologies such as Virtual Reality (VR) and Augmented Reality (AR), leads the charge by turning abstract material into interactive knowledge, and also by presenting abstract knowledge as visible, audible and perceivable dynamic content (Cai, Chiang, Sun, Lin, & Lee, 2017; Dunleavy, Dede, & Mitchell, 2009; Radu & Schneider, 2019). This study designed AROSE (Augmented Reality Optical Simulation Experiments) to provide learners within an interactive optical simulation experiment environment and to promote the development of students’ self-efficacy and conceptions of learning physics.

Literature review
AR’s educational potential and application in learning physics
Although AR-based learning environment is an emerging idea, many of its features are nevertheless deeply rooted within the classical principles of education and psychological theories of learning. For example, (1) Classical behaviorism considers learning is a stimuli-response (S-R) binding formula, in which stimuli are reacted to completed and internalized learning (Watson, 1913). In the AR virtual learning environment, the learner first interacts with the environment, quickly receives feedback, and then, decides their next steps based on the feedback, therefore, establishing a link between the exposed stimuli and response; (2) AR virtual learning environment contains rich constructing toolkits, a multitude of performance venues and better emphasizes learner’s self-control. These are consistent with Piaget’s vision and practice of “moving laboratory into the classroom” (Piaget, 1962) and also fits in the view of Jonassen’s “Learning is a...
real-world experience” constructivist learning theory (Jonassen, 1994). Therefore, the spawn of AR is well-situated within the branches of classical education and its applications.

More recent and pertinent studies regarding learners’ self-efficacy and conceptions of learning show that the application of AR technology in education can significantly enhance educational effectiveness (Garzón & Acevedo, 2019; Garzón, Pavón, & Baldiris, 2019). AR technology can also visualize the microscopic world such that the students can lively observe the composition of distinct matters (Cai, Wang, & Chiang, 2014); to visualize the abstract concepts in general (Cai et al., 2017; Dunleavy et al., 2009); it can even help students memorize factual historical information more effectively (Lim & Lim, 2020). Building on top of the visualization advantages, AR is also powerful in general academic experiences and reformed models of learning. For example, AR technology enhances students’ learning motivation, academic performance, ability to explore and can help avoid conceptual fallacies (Chiang, Yang, & Hwang, 2014). In terms of peer interaction, AR technology supports students’ collaborative inquiry learning and allows students to dive deeper into the inquiry process (Wang, Duh, Li, Lin, & Tsai, 2014). AR has proven to be a powerful and emerging tool in educational technology, with the inertia and the potential to be revolutionary in challenging what counts as technology integration is classrooms of all subjects.

AR in physics education, in particular, is not without predecessors, as multiple scholars investigated its effects since the inception of AR in general. Take Echeverría et al. (2012) as a start—they compared an experimental group with an AR game running on tablet and additional “head-mounted” displays with a control group with a “multiple-mice computer game” running on standard PCs. Results showed that both technologies had a significant effect on learning performance, but there was no statistically significant difference between groups in terms of acquisition. Ibáñez, Di Serio, Villarán, and Kloos (2014) conducted a classroom experiment with 64 high school students to test whether a mobile AR application or a similar web-based application is more effective in supporting the acquisition of physics knowledge. Results indicated that students in the AR group perceived higher levels of flow experience and also acquired significantly more knowledge. Akçayır, Akçayır, Pektaş, and Ocak (2016) investigated the effects of the use of AR in undergraduate level students’ physics lab skills and the result revealed that AR technology significantly enhanced the development of the undergraduate students’ physics laboratory skills. Most recently, Fidan and Tuncel (2019) found that AR-integrated Problem-Based Learning (PBL) increased students’ learning achievement and promoted their positive attitudes towards the subject of physics, which contributed to students’ long-term retention of physics materials. This shows that physics as a core class in middle and high schools have already attracted attention in the field and literature on the properties of AR-based physics is being constructed.

Learning self-efficacy

Bandura (1977) defined self-efficacy as the degree of self-confidence that people can use their skills to accomplish a certain work behavior, and differences in their own success or failure experience, alternative experience, speech persuasion, emotional arousal and situational conditions will have an impact on the self-recognition and evaluation. The degree of difficulty of tasks, the degree of individual effort and assistance from the outside world have a significant impact on the subsequent learning behaviors.

Further research conducted by Bandura (2006) himself shows that self-efficacy as an effective predictor of student learning efficiency and learning motivation can detect subtle changes in students’ academic performance and can also coordinate their learning process. Bandura also found that students’ self-efficacy in terms of academic proficiency plays a crucial role for their motivation. Yusuf (2011)’s survey also found that self-efficacy can directly affect student achievement.
The study by Dinther, Dochy, and Segers (2011) shows that a positively oriented learning experience that provides students with practical experience can lead to a stronger sense of self-efficacy. Liu (2015) chose the path less travelled and designed an innovative, AR-integrated marine learning program and concluded that AR technology can enhance students’ learning confidence, and, therefore, may have some effects on the self-efficacy of learning physics. Cai, Liu, Yang, and Liang (2019) explored another facet of self-efficacy by designing and implementing a series of probability and statistics lessons using tablet-based AR in order to examine its effects. They did so by comparing the conceptions and approaches of learning of middle school students with different levels of self-efficacy, and they found that students with higher self-efficacy would pay closer attention to higher level conceptions and apply more advanced strategies when learning probability and statistics in an AR-inspired classroom. Although no abundant research is done on AR-based physics’ self-efficacy, AR and self-efficacy as a direction has already begun its examinations.

**Conceptions of learning**

Entwistle and Peterson (2004) proposed the idea of conceptions of learning, which refer to people’s beliefs and understanding of the nature of learning and is based on their actual learning experience. Conceptions of learning is different from Bloom’s taxonomy, which is from the perspective of learners’ activities of learning (Fan & Bokhove, 2014). As learning unfolds in specific tasks and contents, the students’ conceptions of learning are also limited to these specific tasks and contents.

Based on this idea, Tsai (2004) used phenomenological methods to investigate the scientific conceptions of learning of Taiwanese students and sorted the learning experiences into seven categories: memorizing, preparing for testing, calculating and practicing tutorial questions, increasing knowledge, applying, understanding and seeing in a new way. These seven categories represent the developmental trend of a person’s conceptions of learning. That is to say, when one is just beginning to learn, one may regard learning as a simple “memorizing,” and with the accumulation of learning experience, one will eventually think that learning is for “applying,” “understanding” and “seeing in a new way.” Tsai, Ho, Liang, and Lin (2011) furthered the aforementioned study and dichotomized these seven categories into lower-level conceptions and higher-level conceptions. The lower-level conceptions include the first three categories in the previous study, which represent passive, fragmented learning. Lower-level conception learners also believe that learning is rote memorizing and simple content reproduction. The remaining four categories from the previous study are considered higher-level conceptions, which represent the process that learners extract content from learning materials and transform it into a more meaningful whole. Some scholars have developed measurement tools to study student’s conceptions of learning in selected subject areas. For example, Chiou and Liang (2012) and Chiou, Liang, and Tsai (2012) used their original metrics to study students’ conceptions of learning science and biology respectively. Since this idea is comparatively new, not much literature is available; however, the dichotomy of conceptions has proven its use in research teaching and learning.

**Research questions**

As previous studies have shown, one can safely generalize that the existing literature have been more focused on the role of AR technology in “improving performance” and “enhancing learning motivation” and have scarcely explored the mechanisms behind such technologies. Motivated by such observation in the current field, this study attempts to examine the impact of AR technology applied in physics education on students’ self-efficacy and conceptions of learning, and attempts to reveal the underlying causes of possible phenomenon. And as thus, the research questions proposed in this study are as follows:
1. Do students’ learning self-efficacy change during the learning process in an AR learning environment? If so, what changed?
2. Do students’ conceptions of learning change in their learning process in an AR learning environment? If so, what changed?

Methods

Experimental tools

In this study, we developed AROSE (Augment Reality Optical Simulation Experiments), a photoelectric effect experimental AR application for the experimental group to explore, while the control group utilized a Flash demonstration for the same material.

AROSE

There are four experiments in AROSE. Experiment 1 gives the macroscopic picture of the photoelectric effect, as shown in Figure 1a. In ordinary classrooms or labs, due to unfavorable light source control and low accuracy of ammeters, the desired phenomenon is often difficult to observe to its optimal quality. AROSE enables this phenomenon to be demonstrated by providing an ideal light control and a highly accurate ammeter.

Experiment 2 shows the microscopic view of the photoelectric effect, which occurs when the power source is off. This is frequently used to analyze the dynamic behavior of photoelectron escape under the power off condition. This is shown in Figure 1b.

Experiments 3 and 4 shows the microscopic phenomenon of the photoelectric effect, this time under different current conditions. This is used to analyze the movement of microscopic particles under different currents, as shown in Figure 1c,d. AROSE provides students with the opportunity to directly observe such phenomena by visualizing concepts that were perceived to be abstract and difficult to demonstrate in ordinary settings.

In order to create such AR learning environments, the researchers used Vuforia SDK, a development software, to build a highly realistic exploration environment which supports natural interaction through programing in the Unity3D environment. To differentiate Unity3D from Flash and other applications, the 3D models used by AROSE do not enlarge the model features but in fact restore them with high precision and the natural interaction between the students and the

![Figure 1: The screenshots of different experiments in the application](wileyonlinelibrary.com)
virtual models is achieved through programing. Students can move and rotate the virtual models by moving and rotating the recognition card. Students press the special areas on the card to control the respective lab equipment in AROSE. Also, students can change the size of the sliding rheostat by moving its slider on the tablet, as shown in Figure 2. In addition, the natural interaction method restores the control methods in the real environment, so that students’ virtual experimental experience can be applied to real life.

In terms of teaching & learning, AROSE promotes students’ independent inquiry in the process of learning physics. In each experiment, the researchers provided the relevant lab equipment virtually and actualized the functions of such equipment through pre-programing and coordination on the recognition card so that the application could present the corresponding experimental phenomenon in real-time correspondence to the students’ operations on the card. Using AROSE can create more experimental opportunities for students and can further enrich students’ practical experience. According to Dinther et al. (2011), practical experience is highly related to positive learning experiences, which can bring learners a stronger sense of self-efficacy. In addition, according to the classification of conceptions of learning by Tsai (2004), the four experiments in this study have a high degree of intrinsic connection. From the macroscopic level to the microscopic, from natural phenomenon to theoretical applications, AROSE can encourage students to acquire knowledge content, inspire discovery and exploration, apply knowledge, and promote a sequential and logical understanding of the material so that they have actively internalize them to a more meaningful whole.

Flash learning tools
The Flash tool consists of three experiments. Experiment 1 simulates the macroscopic phenomenon of transmitting the photoelectric effect, as shown in Figure 3a. Experiment 2 shows the microscopic phenomenon when the photoelectric effect occurs under the condition of power off, which is used to analyze the dynamic behavior of photoelectron in case of power off, as shown in Figure 3b. Experiments 3 and 4 present the microscopic phenomenon of the photoelectric effect under different current conditions, which is used to analyze the movement of microscopic particles under different currents, as shown in Figure 3c. In the Flash environment, students interact with the experiment by clicking buttons on the screen.

Measurement tools
This study used existing scales to obtain quantitative data including the level of students’ self-efficacy and conceptions of learning. The research adopted the measurement scale developed by

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Figure 2: The natural interaction of application [Colour figure can be viewed at wileyonlinelibrary.com]
Tsai et al. (2011) to measure students’ conceptions of learning science (COLS). In Tsai et al.’s study, this survey has principally been designed for Taiwanese high school students and maintained sufficient reliability (overall alpha = .91), suggesting that these factors had highly sufficient reliability in assessing the students’ conceptions of learning physics. The survey included 28 items and each category consisted of four items, including memorizing, testing, calculating, increase of knowledge, applying, understanding and seeing in a new way. Besides, the students’ self-efficacy of learning physics (SEOLP) were measured by the questionnaire modified from Chiou and Liang (2012). The students’ self-efficacy survey was also in sufficient reliability (overall alpha = .94), suggesting that these factors had highly sufficient reliability. This survey concluded with conceptual understanding, higher-order cognitive skills, practical work, everyday application, social communication and academic self-efficacy. The rating scales of both tools were from “strongly disagree” to “strongly agree” and was presented as a 1–5 Likert scale.

Experimental sample
In this study, students from two classes of grade 11 of a high school were selected as the study object. A total of 98 students aged between 16 and 18 years old were randomly divided into an experimental group and a control group, each with 49 students. Both groups of students completed the experiment with Flash/AR teaching tool with the help of the teacher and filled in the same experimental report. Before the experiment, both groups of students learn the related content of wave-particle duality of the light without aid of teaching tools and pretest results showed that there was no significant difference of their performance in the physics learning self-efficacy and dimensions of conceptions of learning.

Experimental procedure
The experimental design for this study is shown in Figure 4. After being introduced purpose of this experiment, all subjects were asked to complete pretest questionnaires to analyze their level of self-efficacy and conceptions of learning physics before the intervention.

Experimental interventions began after the completion of the pretest, lasting for 4 weeks and one lesson per week, as shown in Figure 5. Both classes were taught by the same teacher, as experimental guidance and assistance were provided when necessary. During this period, both groups of students were required to complete an experimental report on site, as shown in Figure 6. During the entire intervention period, except for the different CAI teaching tools (Flash or AR) used, textbooks, tools and other materials used by the two groups of students were the same.

After experiments, all students were required to complete posttest questionnaires.
Results

Compare physics learning self-efficacy of students in AR and Flash groups

In order to determine whether the AR technology affected the self-efficacy of the students towards physics learning, a SEOLP questionnaire was administered to both groups before and after...
the experiment. Before the intervention, no significant difference (p > .05) was found between two groups, as shown in Table 1.

The mean value and standard deviation of physics learning self-efficacy of the two groups before and after the teaching intervention are shown in Table 2. Univariate analysis of covariance (ANCOVA) was used to explore the differences in physical learning self-efficacy between the two groups of students after the intervention. The covariate is the level of self-efficacy before the teaching intervention, so the dependent variable is the self-efficacy after the teaching intervention. At the same time, Table 2 also shows the adjusted mean and variance of the two groups after experimental intervention.

The results of ANCOVA analysis showed that students in the AR group achieved significantly higher scores on physics learning self-efficacy than those in the Flash group. For example, Conceptual understanding (F = 5.614, p < .05, \( \eta^2 = 0.056 \)). Higher-order cognitive skills

Table 1: The t-test scores in SEOLP from the pretest of the control and experimental groups

| Factor | Group  | Mean | SD | T | p   |
|--------|--------|------|----|---|-----|
| SEOLP  | AR     | 2.82 | 0.79| 0.22| .83 |
|        | Flash  | 2.79 | 0.58|    |     |
|        |        |      |    |    |     |
|        | AR     | 3.15 | 0.68| −0.07| .94 |
|        | Flash  | 3.16 | 0.71|    |     |
|        |        |      |    |    |     |
|        | AR     | 2.91 | 0.78| 0.39| .70 |
|        | Flash  | 2.85 | 0.64|    |     |
|        |        |      |    |    |     |
|        | AR     | 2.67 | 0.80| −0.47| .64 |
|        | Flash  | 2.74 | 0.71|    |     |
|        |        |      |    |    |     |
|        | AR     | 2.95 | 0.67| 0.61| .54 |
|        | Flash  | 2.87 | 0.64|    |     |
|        |        |      |    |    |     |
|        | AR     | 2.88 | 0.79| −0.31| .76 |
|        | Flash  | 2.92 | 0.46|    |     |

Note: AR group, n = 49; Flash group, n = 49. CU: Conceptual understanding; HCS: Higher-order cognitive skills; PW: Practical work; EA: Everyday application; SC: Social Communication; AS: Academic self-efficacy.
Table 2: Descriptive statistics of students’ pretest and posttest scores on the Self-efficacy of Learning Physics (SEOLP) and ANCOVA summary

| Factor | Group | Before treatment | | After treatment | | Univariate ANCOVA | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean (adjusted) | Standard error | F | η² |
| SEOLP | CU | AR | 2.80 | 0.79 | 3.12 | 0.82 | 3.14 | 0.09 | 5.61* | 0.056 |
| | | Flash | 2.79 | 0.58 | 2.80 | 0.63 | 2.81 | 0.09 | | |
| | HCS | AR | 3.15 | 0.68 | 3.24 | 0.75 | 3.25 | 0.09 | 7.16** | 0.070 |
| | | Flash | 3.16 | 0.71 | 2.91 | 0.74 | 2.91 | 0.09 | | |
| | PW | AR | 2.91 | 0.78 | 3.15 | 0.87 | 3.14 | 0.11 | 6.07* | 0.060 |
| | | Flash | 2.85 | 0.64 | 2.73 | 0.82 | 2.74 | 0.11 | | |
| | EA | AR | 2.67 | 0.80 | 2.63 | 0.81 | 2.65 | 0.10 | 0.00 | 0.000 |
| | | Flash | 2.74 | 0.71 | 2.67 | 0.81 | 2.65 | 0.10 | | |
| | SC | AR | 2.95 | 0.67 | 3.10 | 0.79 | 3.08 | 0.09 | 3.98* | 0.039 |
| | | Flash | 2.87 | 0.64 | 2.81 | 0.64 | 2.84 | 0.09 | | |
| | AS | AR | 2.88 | 0.79 | 2.86 | 0.81 | 2.87 | 0.10 | 0.41 | 0.004 |
| | | Flash | 2.92 | 0.46 | 2.79 | 0.70 | 2.78 | 0.10 | | |

Note: AR group, n = 49; Flash group, n = 49. CU: Conceptual understanding; HCS: Higher-order cognitive skills; PW: Practical work; EA: Everyday application; SC: Social Communication; AS: Academic self-efficacy.

*p < .05,

**p < .01.
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(F = 7.160, p < .01, η² = 0.070), Practical work (F = 6.075, p < .05, η² = 0.060) and Social Communication (F = 3.976, p < .1, η² = 0.039).

Results indicated that the integration of AR technology into the physics learning environment can enhance students’ physics learning self-efficacy, especially in terms of “Conceptual understanding,” “Higher-order cognitive skills,” “Practical work” and “Social Communication.”

Compare students’ conceptions of learning physics in AR and Flash groups

This study also assessed how the integration of AR technology into the physics learning environment affected students’ conceptions of learning physics. A t-test analysis was conducted on two groups’ pretest scores collected by COLP questionnaire and the results revealed that there was no significant difference between the pretest scores of the control and experimental groups, as shown in Table 3.

In addition, the ANCOVA analysis method was used to explore differences between the two groups of students. The covariates and dependent variables were students’ conceptions of learning physics scores before and after the teaching intervention. Table 4 shows the mean and variance of the adjusted scores of conceptions of learning physics of the two groups of students after the teaching intervention.

The ANCOVA analysis results showed that students in the AR group scored higher in the aspect of higher-level conception of learning than the Flash group, for example, Applying (F = 9.458, p < .01, η² = 0.091), Understanding (F = 4.835, p < .05, η² = 0.48) and seeing in a new way (F = 9.401, p < .01, η² = 0.090). In the two indicators of Memorizing (F = 8.782, p < .01, η² = .085) and Calculating (F = 4.352, p < .05, η² = 0.044), the scores of students in the AR group were significantly lower than those in the Flash group.

The results showed that the integration of AR technology into the physical learning environment enabled students to focus more on the higher-level conceptions of physics learning rather than lower-level conceptions, especially in the “Memorizing” and “Calculating and practicing.”

Table 3: The t-test scores in COLP from the pretest of the control and experimental groups

| Factor | Group | Mean  | SD  | t    | p    |
|--------|-------|-------|-----|------|------|
| COLP   |       |       |     |      |      |
| M      | AR    | 3.30  | 0.91| 0.23 | .82  |
|        | Flash | 3.56  | 0.83|      |      |
| T      | AR    | 2.98  | 1.06| −1.70| .09  |
|        | Flash | 3.32  | 0.93|      |      |
| CP     | AR    | 2.46  | 0.82| 0.54 | .59  |
|        | Flash | 2.37  | 0.77|      |      |
| I      | AR    | 2.46  | 0.95| 2.05 | .43  |
|        | Flash | 2.13  | 0.60|      |      |
| A      | AR    | 2.53  | 0.85| 0.59 | .56  |
|        | Flash | 2.44  | 0.62|      |      |
| U      | AR    | 2.30  | 0.81| 0.45 | .65  |
|        | Flash | 2.23  | 0.61|      |      |
| S      | AR    | 2.14  | 0.91| 0.58 | .57  |
|        | Flash | 2.05  | 0.64|      |      |

Note: AR group, n = 49; Flash group 2, n = 49. M: Memorizing; T: Testing; CP: Calculating and practicing; I: Increasing one’s knowledge; A: Application; U: Understanding; S: Seeing in a new way.
Table 4: Descriptive statistics of students' pretest and posttest scores on the Conceptions of Learning Physics (COLP) and ANCOVA summary

| Factor | Group | Before treatment | After treatment | Univariate ANCOVA |
|--------|-------|-----------------|-----------------|-------------------|
|        |       | Mean | SD  | Mean | SD  | Mean (adjusted) | Standard error | F     | η²   |
| COLP   | AR    | 3.30 | 0.91| 2.88 | 0.84| 2.87            | 0.10           | 8.78**| 0.085|
|        | Flash | 3.26 | 0.84| 3.30 | 0.83| 3.31            | 0.10           |       |      |
|        |        |      |     |      |     |                 |                |       |      |
| T      | AR    | 2.98 | 1.06| 3.13 | 0.97| 3.22            | 0.12           | .33   | 0.003|
|        | Flash | 3.32 | 0.93| 3.22 | 0.97| 3.13            | 0.12           |       |      |
|        |        |      |     |      |     |                 |                |       |      |
| CP     | AR    | 2.46 | 0.82| 2.29 | 0.88| 2.26            | 0.10           | 4.35* | 0.044|
|        | Flash | 2.37 | 0.77| 2.53 | 0.75| 2.56            | 0.10           |       |      |
|        |        |      |     |      |     |                 |                |       |      |
| I      | AR    | 2.46 | 0.95| 2.22 | 0.78| 2.17            | 0.11           | 2.01  | 0.021|
|        | Flash | 2.13 | 0.61| 2.33 | 0.76| 2.38            | 0.11           |       |      |
|        |        |      |     |      |     |                 |                |       |      |
| A      | AR    | 2.53 | 0.85| 2.89 | 0.81| 2.87            | 0.09           | 9.45**| 0.091|
|        | Flash | 2.44 | 0.62| 2.46 | 0.57| 2.49            | 0.09           |       |      |
|        |        |      |     |      |     |                 |                |       |      |
| U      | AR    | 2.30 | 0.81| 2.55 | 0.84| 2.53            | 0.10           | 4.83**| 0.048|
|        | Flash | 2.23 | 0.62| 2.22 | 0.56| 2.24            | 0.10           |       |      |
|        |        |      |     |      |     |                 |                |       |      |
| S      | AR    | 2.14 | 0.91| 2.54 | 0.78| 2.53            | 0.10           | 9.40**| 0.090|
|        | Flash | 2.05 | 0.65| 2.08 | 0.67| 2.09            | 0.10           |       |      |

Note: AR group, n = 49; Flash group 2, n = 49; M: Memorizing; T: Testing; CP: Calculating and practicing; I: Increasing one's knowledge; A: Application; U: Understanding; S: Seeing in a new way.
*p < .05, **p < .01.
Conclusion and discussion
The positive effect of AR on learning performance, attitudes and motivations were convinced in previous studies (Cai, Chiang, & Wang, 2013; Cai et al., 2017; Chiang et al., 2014; Ibáñez et al., 2014). However, few of them pay attention on the mechanisms. In this study, the self-efficacy and conceptions of learning physics were chosen as the key measurements to explain how AR could bring positive effect in the educational context in physics courses. The current research explored the effect of AR technology on the self-efficacy and conceptions of learning physics of Chinese high school students by setting up control experiments. Meaningful results were found in response to both research questions.

In regard to self-efficacy, using AR technology can significantly enhance students’ self-efficacy in physics learning. The current study found that students in the AR group scored significantly higher than those of the Flash group in terms of Conceptual understanding, Higher-order cognitive skills, Practical work and Social Communication. The improvement on Conceptual understanding do make sense because AR’s effect on cognitive (Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012) and deep understanding on the learning topic (Kamarainen et al., 2013) were revealed before. In this study, the characteristics of AR technology that can turn abstract learning content and concepts into lively and perceivable dynamic content. This technology can help in the understanding through reducing students’ cognitive load (Santos et al., 2014), by making phenomenon which cannot be directly observed in reality visualized in the classroom. In our interview with some of the participants after the AR lesson, one participant reflected, “By using this software, I can really see the electronic movement. Oh, I can’t imagine it at all in the classroom.”

The Conceptual understanding of students could describe students’ confidence in using cognitive skills in learning (Wang, Liang, Lin, & Tsai, 2017). Thus, the improvement on understanding on the conception level would bring Higher-order cognitive skills. At the same time, AR technology can create a highly immersive learning environment so that students can place themselves in experiments. This environment gave students a stronger sense of relevance and allow them to interact with the virtual objects, enhancing students’ sense of identity with the observed phenomena. Another participant commented after one AR lesson, “The teacher usually asked us to find some video animations. Every time I see the same phenomenon. Who knows if these are fictional? In this AR software, I can actually change the parameters and see different movements.” Through interactive activities, cooperation and reflection, students can improve their understanding of their own abilities, thereby enhancing students’ sense of behavioral accomplishment and their learning self-efficacy. These improvements could explain how AR can affect students’ learning performance through the view of learning self-efficacy in physics.

As for the second research question—in terms of conceptions of learning physics—integrating AR technology into physics classrooms can promote the generation of high-level conceptions of learning. The experimental data showed that compared with the level of students’ conceptions of learning in the Flash group, students in the AR group performed significantly better in high-level conceptions and scored significantly lower in some low-level conceptions. One of the major differences between AR and Flash is its interactivity. Screens of Flash virtual experiment are all computer-generated virtual screens and have nothing to do with the student’s actual environment. Flash can only play the role of experiments demonstration without getting rid of the button-and-mouse and locating students in the experimental situation. In comparison, the AR learning environment provides students with natural interaction and feedback information in real-time. This allows students to experience the immersion of playing games and brings students
into a more realistic experimental environment (Cai et al., 2017), so students pay more attention to the experiment itself and the inquiry process.

Therefore, AR virtual experiments can lead students to be more concentrated on high-level conceptions of learning physics than on low-level conceptions. The learning of physics requires students’ developing of high-level conceptions, such as application, understating and seeing in a new way, rather than the low-level conceptions, such as testing. The better performance on the high-level conceptions of experimental group also confirms this view.

More qualitative evidence exists to support generalization of AR. In some randomly selected interviews with participants from the experiment group after one AR-lesson, it is found that most participants interviewed held a high evaluation of the AR learning environment. Some of these participants expressed the desire to bring this type of learning into other learning contexts. One wondered, “Is there any learning software targeted for the chapter of chemical microcosm. I don’t understand the distribution of extranuclear electrons explained by the teacher.”

This finding is in accordance with some previous studies, where Lu and Liu (2015) pointed out that students had a positive learning attitude towards the instructional activity, appearing relaxed, happy and playful as they learned through play and Chiang et al. (2014) found that AR technology provided timely and relevant information that can provide guidance for student learning and improve their learning motivation.

In summary, this study developed specialized AR teaching tool and applied it in physics education. The experimental results showed that the AR assisted experiments can significantly enhance students’ self-efficacy in physical learning; they can lead students to be more concentrated on high-level conceptions of learning physics rather than low-level conceptions. For the future research on AR’s application on physics, the design of the application and learning activities should pay more attention on students’ high-level conceptions. One lesson from this study is that AR should be designed for inquiry process rather than presentation. The ability of AR in adjusting parameters and observing phenomena in real-time should be taken into more virtual experiments crated by AR.

It should also be brought to the practicing educator’s attention that AROSE is not ephemeral in terms of theoretical application. Integration of AR into teaching and learning can be applied to multiple subjects in traditional teaching & learning, such as secondary mathematics, secondary chemistry and elementary natural sciences (Cai et al., 2017, 2019, 2014). Instead of an array of class artifacts that is bought in sets and used once for twice throughout the school year for the particular lesson, we can simply get one tablet and install different applications on an as-needed basis. Just as we realize that optics is often a difficult topic in physics to learn, there can be other topics in other subjects that is historically challenging for the students. More future research can be conducted in investigations of other applications, striving towards the goal to broaden the purview of AR and increase the accessibility of this technology.

However, limitations of the application in this study do exists. On the one hand, the technology could be improved in this research. A few students made suggestions for further improvement of using AR in teaching scenarios. A student said, “When you touch the card with hand, it is occasionally not sensitive. You have to move it away and put on again.” This is because the button interaction of the AR is based on natural optical technology and the interaction stability of the software should be further improved. On the other hand, the research questions could be more in-depth in future research. The road of AR in education is long, yet AROSE already is yielding so many promising results and next steps. As researchers and practitioners work together to identify challenges and
produces solutions, we hope that we can iterate classroom teaching and learning to align with the ever intelligent and inter-connected world.

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Statements on open data, ethics and conflict of interest
We accessed all the questionnaire data from students in one high school. All the students had been informed that their responses on the questionnaire were used for research only. We use SPSS to analysis the data. If you want to get the original data collected in this research, please email the corresponding author and we will provide it to you.

This research was carried out under the ethical guidelines. We took an experiment in a high school and we informed all the participants the basic information about the research and we got the permission to use these data for our research. To ensure confidentiality, students’ personal identifiers were removed prior to processing the data.

The authors declare no conflict of interest in the submission of this manuscript and the manuscript is approved by all authors for publication. I would like to declare on behalf of all the co-authors that the work described is original research that has not been published previously and not under consideration for publication elsewhere, in whole or in part.

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