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Mitigating the Urban-rural Digital Divide: A Dual Scaffolding-embedded Mobile Augmented Reality Learning Approach in the Post COVID-19 Pandemic

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ABSTRACT: Mitigating the digital divide is essential for the sustainable development of education. To provide distance access which ensures equality in education for both urban and rural students, online learning has been emphasized in the post COVID-19 period. However, some challenges to total online learning have been described, such as isolation and the lack of in-time interaction due to the separation between teachers and students. The mobile augmented reality (AR) learning approach has the potential to combine real-world and online objects to promote interaction in total online learning. However, researchers have found that teachers and students might feel frustrated while handling too much information to deal with complex tasks in AR learning without appropriate scaffolding, which might reinforce the digital divide. Therefore, there is a need to propose a dual scaffolding-embedded AR learning approach to mitigate the urban-rural digital divide rather than a single form of scaffolding for either teachers or students. A quasi-experiment was conducted by recruiting 173 sixth-grade students from four classes of urban and rural schools in southern China. The longitudinal results showed that the proposed approach effectively improved both urban and rural students' learning achievement, higher-order cognition, and self-efficacy. The comparison of the students' learning outcomes indicated that it was helpful to mitigate the digital divide between rural and urban students through the proposed approach. These findings provide insights for school administrators to provide relational and suitable scaffolding-embedded mobile AR learning to support total online education for mitigating the urban and rural digital divide in the post COVID-19 period.

Keywords: Digital divide, Mobile, Augmented reality, Scaffolding, Outcomes

1. Introduction

Education equity, one of the core values of sustainable development of education, is proposed in Sustainable Development Goal 4 of the 2030 Agenda to "ensure inclusive and equitable quality education" (UNESCO, 2017). One form of educational inequity is the divergent gains from education during the COVID-19 pandemic that exist between urban and rural settings. Researchers have indicated that technology education could help mitigate the urban-rural digital divide by overcoming some of the strong forces that lead to educational inequalities (Zilka, 2021). Scholars have pointed out that all members participating actively and thoughtfully in the online learning environment enabled effective practices during the COVID-19 pandemic (Carrillo & Flores, 2020). Therefore, online education in the post COVID-19 period has the potential to provide the same equality in education to mitigate the digital divide between urban and rural settings.

Scholars have indicated that total online learning brought some challenges due to the unequal access to technical resources, digital literacy, a feeling of nihility, the poor state of autonomous learning, and a lack of in-time interaction with the separation between teachers and students, thus further widening the digital divide between urban and rural settings during the post-COVID-19 period (Laufer et al., 2021; Palau et al., 2021; Romero-Hall, 2021). In other words, total online learning may fail to achieve the expected teaching objectives in the post COVID-19 period if the design of online education is not appropriate. One form of educational inequity is unequal learning gains from online and blended education between urban and rural settings during the COVID-19 pandemic, which can be regarded as the new urban-rural digital divide. The mobile augmented reality (AR) technology-assisted learning approach provides a solution to mitigate the new urban-rural digital divide in total online learning during the COVID-19 pandemic. AR refers to the technology which integrates virtual and real worlds, and which provides an interactive and immersive experience (Seo & So, 2022). Research has found that the mobile AR technology-assisted learning approach could combine real-world and online objects, assisting users in interacting with online objects in real time to reduce loneliness and isolation from total online learning during the COVID-19 pandemic (Lin et al., 2022a). In other words, the mobile AR technology-assisted learning approach offers a significant advantage of overlapping the real world with online information in real time. Therefore, the mobile AR technology-assisted learning approach provides the potential to address the barriers (e.g., the feeling of nihility, the poor state of autonomous learning, and the lack of in-time interaction) for teachers and students during the post COVID-19 period in total online learning due to the separation of teachers and students. In addition, mobile technology-assisted AR is regarded as one technology that can help students develop cognition and motivate them to learn during the learning process (Chou et al., 2021). It has enormous potential for the fair distribution of educational resources to mitigate the urban-rural digital divide. Research has verified that the mobile AR technology-assisted learning approach could reduce the effects of individual differences (Chen & Wang, 2015).

Although the mobile AR technology-assisted learning approach could meet teachers' and students' need to mitigate the urban-rural digital divide, teachers and students may feel frustrated when handling plentiful information to deal with complex tasks in mobile AR learning. Other challenges to mobile AR learning that may cause a new education gap between urban and rural settings have been indicated, such as poor use of AR resources for teaching (Alalwan et al., 2020; Alkhattabi, 2017), and the lack of guidance or prompts for students (Extremera et al., 2020). Previous studies have emphasized the significance of the provision of proper scaffolding to address the challenges to teachers' and students' mobile AR learning (Alkhattabi, 2017; Lin et al., 2020). Multi-dimensional scaffolding, including cognitive scaffolding, metacognitive scaffolding, and peer scaffolding, has the potential to solve the problems of teachers and students when applying the mobile AR technology-assisted learning approach (Hou & Keng, 2021; Lin et al., 2020).

However, as far as we know, no studies regarding both teachers' and students' scaffolding-based AR learning approach to mitigate the urban-rural digital divide in the post COVID-19 period have been presented. Most previous studies have paid attention to using a single form of scaffolding for either teachers or students (Ibanez et al., 2016; Lin et al., 2020; Tsai & Huang, 2014) in AR learning rather than integrating dual scaffolding into AR-based learning to achieve the expected outcomes. To address this research gap, a dual scaffolding-embedded AR learning approach for teachers and students is proposed to narrow the urban-rural digital divide in the post COVID-19 period. Dual scaffolding is defined as scaffolds (e.g., peer scaffolding, problem-assistance scaffolding, and metacognition-awareness scaffolding) that focus on interactions that occur when teachers and students can use in the mobile AR environment. The interactions that are integrated into mobile AR learning can be divided into two types: interaction between teachers and students, and interaction between humans and AR content. The unique attribution of this study was to incorporate dual scaffolding for the interactions that occurred between teachers and students when they engaged in mobile AR learning. Two important aspects of teachers' or students' scaffolding could provide some suggestions for mitigating the urban-rural digital divide in the AR learning process. From the perspective of scaffolding for teachers, Tsai and Huang (2014) indicated that scaffolding is an effective form of assistance for novice and experienced teachers in a mobile AR environment to support teaching material management. From the perspective of scaffolding for students, Hou and Keng (2021) developed a framework of an alternate reality-based board game for AR exploration with multi-dimensional scaffolding, including cognitive scaffolding, metacognitive scaffolding, and peer scaffolding, designed to help students focus on spatial and logical thinking. Therefore, this study developed a dual scaffolding-embedded mobile AR learning approach to mitigate the urban-rural digital divide during the post COVID-19 period. To evaluate the effectiveness of the proposed approach, a quasi-experiment was conducted by using an intelligent AR environment platform. The research questions are as follows:

- Q1: Can the dual scaffolding-embedded mobile AR learning approach benefit students by enhancing their learning achievement to mitigate the urban-rural digital divide?
- Q2: Can the dual scaffolding-embedded mobile AR learning approach enhance students' higher-order cognition to mitigate the urban-rural digital divide?
- Q3: Can the dual scaffolding-embedded mobile AR learning approach promote students' self-efficacy to mitigate the urban-rural digital divide?

2. Literature review

2.1. Mitigating the urban-rural digital divide

Mitigating the urban-rural digital divide refers to better quality education outcome equity that can ensure students from urban and rural settings, irrespective of their socioeconomic backgrounds, gender, area, or other characteristics, have the digital education they need to achieve certain outcomes (Nachbauer & Kyriakides, 2020). Mitigating the urban-rural digital divide is essential to remove the educational inequity to achieve educational equality. Mitigating the digital divide between urban and rural settings has become a widely-discussed issue involving educational facilities and digital teaching resources (Kuo et al., 2021). It can engage students in urban and rural schools in situating and interacting to achieve academic achievements and develop their cognition. Empirical results regarding education divide diminishment have shown that when teachers exhibit a higher degree of integration between online learning course operation and the digital characteristics of online learning courses, the level of the rural-urban education divide could decrease (Hsieh, 2017). Thus, the effective application of online learning has prompted unprecedented attention to mitigate the digital divide during the COVID-19 pandemic.

However, some scholars have highlighted inequalities related to the digital divide (unequal access to technical resources) and the new digital divide (differing levels of digital skills) (Ritzhaupt et al., 2020). In addition, researchers have discovered that the digital divide was more likely to appear in public schools and rural areas (Palau et al., 2021). For example, teachers had difficulties self-regulating their work for online education (Laufer et al., 2021; Palau et al., 2021). Students may lack digital literacy and in-time interactions, and have poor self-regulation for online learning. Previous researchers tended to choose crucial and convenient factors for testing the effect of mitigating the urban-rural digital divide from the perspective of learning achievement (Charalambous et al., 2018), space accessibility (Wang et al., 2021), and attitude (Lin et al., 2022b). However, there is an urgent need to explore an effective approach to facilitating students' higher-order cognition tendency and self-efficacy to equip students with skills and motivation to overcome the challenges of the urban-rural education gap in the next generation. In other words, the combination of learning achievement, higher-order cognition tendency, and self-efficacy may allow researchers to attain the best of the new while retaining the best of the old when exploring the effect of mitigating the urban-rural digital divide. Students' achievement, recognition ability, self-efficacy, and literacy levels have also been used to measure the urban-rural digital divide (Kyriakides et al., 2021; Penuel & Watkin, 2019). Accordingly, this study utilized students' academic achievement, degree acquisition, ability, and literacy improvement to evaluate the urban-rural digital divide.

2.2. Mobile AR learning

Batdi et al. (2018) found that the integration of technology into education to support the teaching and learning process, such as mobile AR technology, as a learning approach, has a positive effect on students' academic achievement. Some previous research has proved the effects of mobile AR technology on promoting students' learning outcomes, such as students' learning achievements (Extremera et al., 2020), positive learning attitudes, and higher-order thinking capacity (Dunleavy et al., 2009), which mitigates the urban-rural digital divide. Mobile AR technology has been shown to facilitate interactive learning in practice, implying that mobile AR technology as information technology has the potential to mitigate the urban-rural digital divide. Lin et al. (2015) developed an AR-assisted learning system to assist junior high school students in learning solid geometry, and found that it could improve students' spatial perceptions. Moreover, AR has a better effect on students with higher self-efficacy (Lin et al., 2020). Despite the potential advantages of AR in mitigating the urban-rural digital divide, most previous studies have focused on the function of interactive situational resources in a real-world environment, implying the main benefits of perceiving and comprehending pre-packaged information (Me & Hsu, 2015). Such a learning experience may confuse users when the real-world target and the digital information mismatch, implying the significance of integrating a teaching support tool into a mobile AR environment (Wu et al., 2018). In this study, AR is considered as a technology that utilizes mobile and context-aware devices (e.g., smartphones, tablets) to enable participants to interact with digital information embedded in a real-world environment in real time (Seo & So, 2022).

Although mobile AR technology-assisted learning could be an effective approach to match the need for weak schools in rural areas to mitigate the urban-rural digital divide, there are some learning and teaching difficulties if the approach is not used properly. In AR-based digital divide between urban and rural settings, two bodies of research can be found on teachers and students to help us identify the learning and teaching difficulties. On the one hand, students may have difficulties with learning effectiveness due to cognitive overload, misconceptions, and the lack of effective reflection prompts. Some students may not complete interactive tasks because they may suffer from cognitive overload when using AR situational interactive resources (Extremera et al., 2020). Cognitive overload may have a negative effect on students' AR learning effectiveness (Akcayir & Akcayir, 2017; Chen, 2020). Chen (2020) has declared that if the refection prompts only give feedback to students at a knowledge level, AR may fail to significantly enhance their learning achievements with refection prompts. In other words, when students receive too much real and online information in the AR learning environment, their learning effectiveness is negatively influenced due to cognitive overload. However, previous researchers have suggested that using multi-dimensional scaffolding (e.g., cognitive, metacognitive, and peer scaffolding) can address students’ spatial and logical thinking difficulties in AR-based learning (Hou & Keng, 2021). On the other hand, one important difficulty for teachers in AR-based teaching is the lack of effective supporting scaffolding. Teachers may have trouble addressing the unintended AR technical problems because of three main difficulties: lack of human infrastructure and IT skills, lack of appropriate ICT infrastructure, and resistance to change (Alkhattabi, 2017). To solve the teaching difficulties of lacking effective supporting scaffolding, previous studies have revealed that the combination of scaffolding theory and AR technology could be useful for teachers to access material management with interaction and convenience for using AR effectively (Tsai & Huang, 2014). In other words, scaffolding can be embedded into the AR-based learning environment to solve these problems for teachers and students to support learning and teaching effectiveness for mitigating the urban-rural digital divide.

2.3. Scaffolding

Scaffolding is defined as support that enables somebody to solve a problem, carry out a task, or achieve a goal beyond their unassisted efforts (Kim & Hannafin, 2011). Shin et al. (2020) demonstrated that student perceptions of the usefulness of hard, peer, and teacher scaffolds may positively impact students’ academic achievement and group performance in inquiry-based technology-enhanced learning activities. Some have discovered that appropriate technology-based scaffolding can potentially encourage more reflective and elaborative discourses, which can assist students’ task-related interaction with regard to problem solving (Ak, 2016). In this study, scaffolding can be defined as assistance from a more knowledgeable person who helps learners do a learning task beyond their capability in a technology-enhanced learning environment.

However, to the best of our knowledge, there are no studies integrating dual scaffolding into AR-based learning to mitigate the urban-rural digital divide. Most existing studies focus on using a single form of scaffolding for teachers or students in AR learning to mitigate the urban-rural digital divide, rather than combining AR with dual scaffolding. To address this research gap, a dual scaffolding-embedded mobile AR learning approach is proposed to mitigate the urban-rural digital divide and to promote students’ learning achievement, cognition, and self-efficacy. The integration of dual scaffolding for teachers and students and mobile AR learning is the most significant feature of this study. Three categories of studies on scaffolding provide evidence for students or teachers to mitigate the urban-rural digital divide in the mobile AR environment.

On the one hand, researchers have incorporated effective supporting scaffolding into AR to promote teaching and learning effectiveness from teachers’ perspectives (Lin et al., 2020; Tsai & Huang, 2014). Lin et al. (2020) indicated a need to apply both reflective scaffolding and technology-assisted (e.g., AR-based) teacher support to help students modify their misunderstandings. Tsai and Huang (2014) emphasized that providing a material management scaffolding tool was effective for novice teachers and experienced teachers in a mobile AR learning environment. However, since the current AR system is usually designed by technology developers, it is difficult to fully meet the needs of teachers when they have to conduct student activities in a mobile AR environment, which indirectly affects students’ education outcomes, reduces their learning motivation, and increases their learning confusion. Therefore, the teaching scaffolding for teachers has potential value to mitigate the urban-rural digital divide in a mobile AR-based environment, effectively assisting teachers’ teaching.

On the other hand, to address the difficulties of students in terms of their learning effectiveness, scaffolding could be applied to improve the students’ learning achievement, cognition, and self-efficacy. There is a great deal of research on scaffolding for students using mobile AR technology. Hou and Keng (2021) developed collaborative scaffolding to guide students’ discussion, and cognitive scaffolding in an AR-based educational board game, allowing students to obtain feedback and additional clues for improving their cognitive ability. Scholars have indicated the importance of providing scaffolding to reinforce students’ knowledge construction and cognitive process in a mobile AR environment (Ibanez et al., 2016). Sezen-Barrie et al. (2020) indicated that using cognitive scaffolding could promote interactions with students in the classroom across time and space. Therefore, the learning scaffolding for students could help them learn effectively to mitigate the digital divide between urban-rural settings in AR-based learning.

Besides, although a single form of scaffolding could help teachers or students in AR-based learning, there is a gap between teachers and students, which could further reinforce the urban-rural digital divide. Lai et al. (2016) indicated differences between teachers and students in terms of their mobile learning environmental preferences. They found that teachers pay attention to technical problems while students focus on rich and useful learning content. Additionally, the AR learning environment enables students to focus more on memorizing, calculating, and practicing (Cai et al., 2021; Lin et al., 2020). Teachers are engaged in designing more effective activities with an AR-based flipped learning guiding approach and interactions with peers to improve their learning motivation, critical thinking tendency, and group self-efficacy (Chang & Hwang, 2018). Thus, there is a need to engage scaffolding to bridge the gap between teachers and students. This scaffolding should ensure that the teachers' teaching approach could match students' learning requirements to mitigate the digital divide between urban and rural settings (e.g., cognition, problem-solving, and self-efficacy). Scaffolding services for teachers and students in the design of mobile AR systematic situational interactive resources should be able to satisfy the functions of teachers' guidance and students' independent exploration. Accordingly, teachers could help students adjust their learning behaviors and improve their academic achievement through dual-scaffolding strategies. To sum up, the above research evidence verifies that a single form of scaffolding has the potential to match the need of teachers or students to mitigate the urban-rural digital divide.

In light of this, there is a need to conduct a dual scaffolding-embedded mobile AR learning approach to mitigate the urban-rural digital divide. In an attempt to improve this situation, this study integrated learning scaffolding on both the teacher-side and student-side system operation, and incorporated the teaching scaffolding service mechanism in the teacher-side operation to mitigate the urban-rural digital divide. Besides, we developed a dual scaffolding-embedded mobile AR learning system to meet the scaffolding service for teachers' teaching and students' learning in the mobile AR environment during the construction of the approach.

3. The dual scaffolding-embedded mobile AR learning approach

This study proposed a dual scaffolding-embedded mobile AR learning approach, providing the scaffolding service for both teachers and students. Accordingly, a dual scaffolding-embedded mobile AR learning system (Figure 1) was developed based on the proposed approach, including the dual scaffolding mechanism, the mobile AR mechanism, and the cloud database. First, the dual-scaffolding mechanism enabled students to complete the learning tasks with the guidance of peer scaffolding, problem-assistance scaffolding, and metacognition-awareness scaffolding. It could help teachers monitor the progress of the activity and guide each student's learning progress with the assistance of scaffolding of problem situations, guidance, feedback, and reflection.

In addition, the mobile AR mechanism had five functions as follows: (1) embedding many different AR models; (2) greatly shortening the production cycle of AR resources for teachers in urban and rural areas; (3) achieving an AR effect that meets the teaching objectives; (4) testing students' mastery of knowledge; and (5) providing students with a better understanding of the learning knowledge through interacting with the AR model. The teacher used Dream Editor (i.e., AR application production software) to quickly integrate the AR model into completed teaching resources with the mobile AR mechanism; it did not require a professional programming language. Finally, the cloud database enabled various data (e.g., scaffolding service data, AR-related data, etc.) to connect, recording students' learning data and teachers' teaching data with technologies.

The experimental group used a dual scaffolding-embedded mobile AR learning system which can realize the interaction between students and AR resources. For example, on the group activity page in the upper left of Figure 1, students can click the AR button to open the AR resource of the flower structure, which can be rotated to present a complete view of the flower structure. During this process, it has annotations and voice explanations to facilitate understanding of the flower structure. Students can add corresponding colors to each part of the flower. Moreover, students can also upload their understanding of the structure of flowers by scanning the QR code below.

We developed the ISEED 3.0 platform to construct and achieve the approach, matching the requirement of teachers' top-down teaching goals and students' bottom-up learning goals. The ISEED 3.0 platform is the third iteration of the ISEED platform, and can be used for free by teachers and students in Southern China. This platform was purchased by the Provincial Education Department. All the applications are implemented on that platform, and the details about the ISEED platform were documented in our previous publication (Lin et al., 2020). Besides, we put forward the goal-driven approach (e.g., top-down analysis, decomposition, and refinement) and bottom-up approach (e.g., emergence, fusion, and self-organization) as two implementation methods to ensure the efficient dual-scaffolding matching analysis between the teaching and learning scaffolding. The scaffolding service varies from person to person and from time to time; it requires the application of complex network analysis and a looping optimization algorithm of genetic algorithm heuristic rules. Additionally, a multi-dimensional and multi-layered dual-scaffolding analysis the interactive network of which is composed of big data is also needed. Considering the exponential complexity of the call and combination algorithm of teacher-student scaffolding teaching service in a mobile AR environment, the more complexity the problem is, the more difficult finding the optimal solution for a polynomial-time becomes. The processes of population initialization, termination condition judgment, genetic operation, chromosomal evaluation, and new population generation are realized in five iterative cycles. To realize the steady-state processing of the teacher-student scaffolding service, we can obtain the fast combination and call of the optimal dual-scaffolding matching in the current domain of learners.

Figure 1. The dual scaffolding-embedded mobile AR learning system

The function of the dual scaffoldings-embedded mobile AR learning system can realize the interaction between students and AR resources. For example, on the group activity page in Figure 1, students can click the AR button to open the AR resources of the flower structure, which can be rotated and present a complete view of the flower structure. During this process, it has annotations and voice explanations to facilitate understanding of the flower structure. At the same time, students can add corresponding colors to each part of the flower. Moreover, students can also upload their understanding of the structure of flowers by scanning the QR code below.

4. Method

4.1. Participants

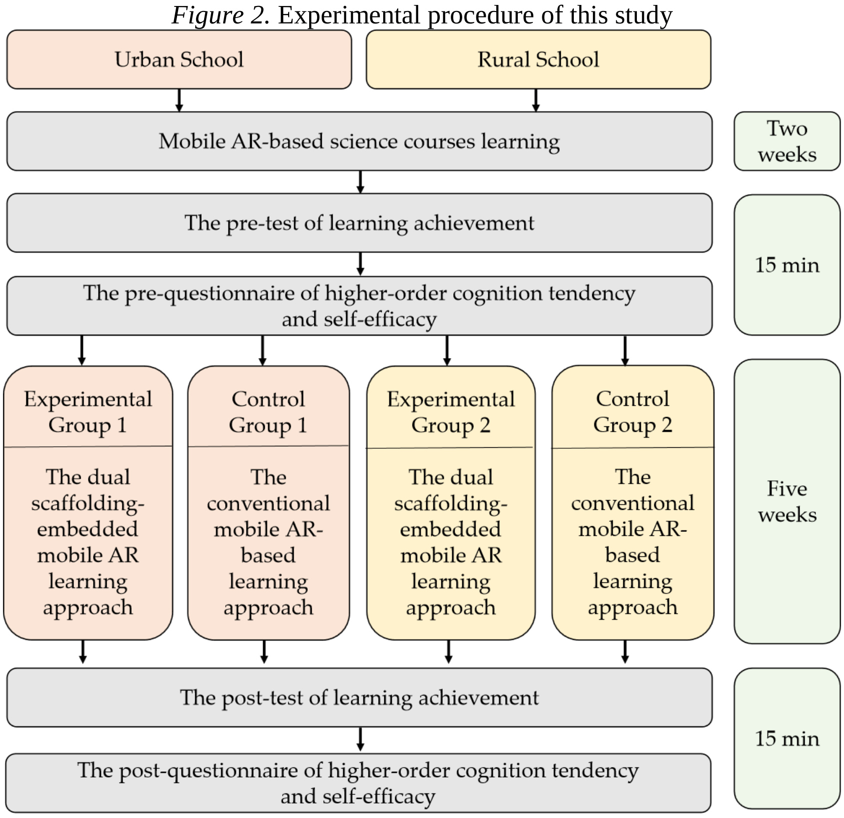
This study recruited 173 sixth-grade students from four classes of urban and rural area schools in southern China. None of the participants had any prior experience of using AR. To ensure that all participants had the same AR learning experience, they were required to complete AR-based science courses. Accordingly, participants were qualified to take a series of more advanced courses, using mobile phones to integrate the dual-scaffolding AR matching mechanism. Therefore, all participants had previous exposure to AR learning projects, in which mobile devices were used for teaching and learning (i.e., the projects occupying more than one-third of the class time).

The students of both schools were divided into two groups. One class was set as the experimental group and learned using the proposed approach, and the other class was set as the control group and learned using the conventional AR-based learning approach. The experimental group consisted of 86 students (mean age = 11.25 years, standard deviation = 1.60). The control group consisted of 87 students (mean age = 11.70 years, standard deviation = 0.98).

4.2. Experimental procedure

The experimental procedure of this study is illustrated in Figure 2. Both groups took 2 weeks of AR-based science courses on this subject until they were used to the mobile AR environment. In addition, both groups of students adopted identical mobile AR learning resources to learn the content of flower structure instructed by the same teacher. Furthermore, all the students from each group were required to finish the pre-test of learning achievement and the pre-questionnaire of higher-order cognition tendency and self-efficacy for 15 minutes. Students from both groups were asked to complete the post-test of learning achievement and the post-questionnaires for 15 minutes to examine their learning achievement, higher-order cognition tendency, and self-efficacy with the different learning approaches. The intervention was administered to both groups for 5 weeks. Specifically, both groups received the teacher's feedback to clarify their misconceptions before the next learning activity to achieve the same learning objectives of cognitive concept, inquiry learning, and innovative design with different kinds of assistance scaffolding.

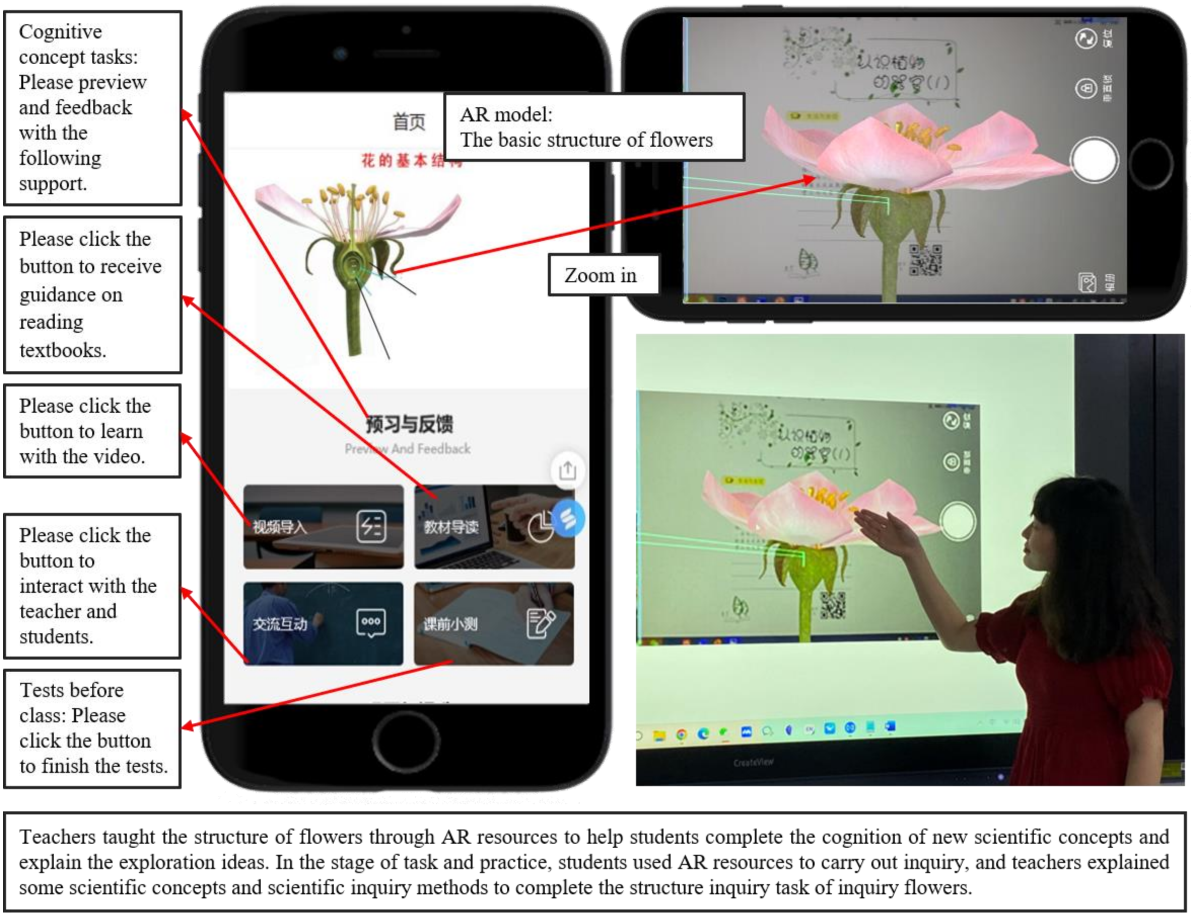
Figure 2. Experimental procedure of this study



Each group of students adopted different mobile AR learning approaches with and without dual scaffolding. The experimental group operated the dual scaffolding-embedded AR learning approach. In this experimental group, students participated in peer scaffolding, problem-assistance scaffolding, and metacognition-awareness scaffolding. In addition, the teacher in the experimental group conducted teaching activities with the assistance of problem situations scaffolding, feedback scaffolding, and reflection scaffolding. The control group employed the conventional AR-based learning approach to complete the learning tasks, as demonstrated in Figure 3. In the control group, the students learned new concept knowledge and construction in the mobile AR environment to complete the tasks about the learning content without learning scaffolding. Furthermore, the teacher in the control group implemented teaching activities without the guidance of teaching scaffolding.

The experimental group applied dual-scaffolding to achieve the cognitive concept learning objective. First, the students sought help with problem-assistance scaffolding when they found difficulties using AR resources for concept learning. Second, the teacher addressed students' misunderstandings with online answering and in-class typical problem discussions. Third, the teacher consolidated students' knowledge with the activities, such as explaining words and answering questions. On the contrary, the control group adopted the conventional AR-based learning approach. First, the students were asked to read the AR teaching resources to understand new concepts under the step-by-step teacher guidance. Second, the teacher asked students to answer thinking questions. Third, if students met problems in the class exercises or in absorbing the new knowledge, the teacher could clarify the students' misunderstandings in detail.

Figure 3. Conventional mobile AR learning system



Then, in the experimental group, the teacher guided students in each learning group to explore problem-based situation scaffolding. Therefore, students in the experimental group could complete the project observation, group collaborative inquiry tasks, and simulation experiments with metacognition-awareness and peer scaffolding. Unlike the experimental group, the teacher in the control group might conduct thematic observations by guiding students to identify similarities and differences between the AR model and the observation in reality. Then, students in the control group could imitate the teacher's experimental steps to reproduce the specific learning process with AR learning resources for completing the experimental thinking exercises in groups.

Lastly, all students tried to promote the comprehensive application of knowledge. For example, all the students from each group were required to design an outdoor practice for Li Lei (i.e., a person in the task) to help him clarify the similarities and differences among different flowers' structures. Based on this theme, the teacher in the experimental group conducted the innovative design of asking students to design the above outdoor practice with the problem-assistance and metacognition-awareness scaffolding. However, students in the control group needed to use their existing knowledge to design outdoor practice under the teacher's guidance to facilitate their understanding of the abstract concepts.

4.3. Data collection

4.3.1. The pre-test and post-test of learning achievement

This study used knowledge test learning achievements and questionnaires to examine students' learning performance. The pre-test and post-test of learning achievement included questions that three science experts validated; sample questions appearing in each test are respectively shown below:
(a) Pre-test sample question: Li Lei's sunflower seeds have been planted for a week but haven't sprouted yet. How can we solve this problem?

(b) Post-test sample question: Li Lei wanted to pollinate the sunflower artificially, so from which part of the flower would he take out the pollen?

4.3.2. Higher-order cognition tendency questionnaire

The questionnaire was modeled after the original students' higher-order cognition tendency scale developed by Lai and Hwang (2014), which included three subscales: complex problem-solving tendency (6 items), meta-cognitive awareness (10 items), and creativity tendency (6 items). The questionnaire included 22 items that were rated on a 5-point Likert scale. The Cronbach's alpha values of the subscales were 0.90, 0.87, and 0.91, respectively. This questionnaire was used to investigate students' complex problem-solving tendencies (e.g., I can use the approach learned in AR science class to solve practical scientific problems), meta-cognitive awareness (e.g., In AR science class, I can find out the reasons for the failure of the inquiry experiment), and creativity tendency (e.g., I can design a new experimental idea through the virtual experiment in AR science class to verify my conjectures about some scientific phenomena) in the process of completing tasks in a mobile AR environment.

4.3.3. Self-efficacy questionnaire

Self-efficacy can be described as an individual sense of self-ability to accomplish the given tasks and achieve the designated performance (Bandura, 1997). Students with high self-efficacy tend to adopt deep learning strategies to gain better academic achievements (Feldon et al., 2018). To further explore whether the introduction of AR situational interactive learning resources used in each group could affect students' learning self-efficacies, the AR learning self-efficacy scale was modeled and modified based on the original learning self-efficacy scale (Lin et al., 2019). An example item is "With the virtual experiment in AR science class, I have understood the scientific concepts taught in the course." The scale has five items, and all items are rated on a 5-point Likert scale. The Cronbach's alpha value was 0.92 in this study. The value indicated that the AR learning self-efficacy scale is reliable to use.

4.4. Analysis

The statistical analysis was performed to test the effect of the proposed approach, which was assisted by the integration of educational technology and the dual scaffolding, on urban and rural students' learning achievement, higher-order cognition, and self-efficacy by using SPSS 21 (IBM). The four groups of students were situated to learn in the different areas (i.e., urban or rural) and with the different AR-based learning approaches (i.e., the dual scaffolding-embedded mobile AR learning approach or the conventional mobile AR-based learning approach). To explore the effect of the proposed approach on the four groups, a two-way analysis of covariance (ANCOVA) was conducted on the post-test by considering the pre-test scores as the covariance. Before the ANCOVA test, the homogeneity of variance assumption and regression coefficients were tested to examine whether variances across samples were equal. The partial eta-squared ($\eta 2$) and Cohen's d were calculated to determine the effect size (small < 0.2, medium 0.2 ~ 0.5, and large > 0.8) (Cohen, 1988).

5. Results

5.1. Learning achievement

Before ANCOVA, Levene's test for learning achievement was not significant ($p > .05$). Therefore, the homogeneity of variance assumption could be verified. In addition, the assumption of homogeneity of regression was not violated ($F = 6.35$, $p > .05$). As shown in Table 1, the result showed that the effect on the interaction between learning approaches and areas was not significant ($p > .05$). Therefore, it was sensible to evaluate the main effects of the dependent variables. The two-way ANCOVA result indicated that a significant effect and a moderate effect size ($\eta 2 > 0.059$) were proved for the learning approaches ($F = 12.23$, $p < .01$, $\eta 2 = 0.13$) and for the area ($F = 5.56$, $p < .05$, $\eta 2 = 0.063$) on students' learning achievement.

Table 1. ANCOVA results of students' learning achievement

Source	*SS*	*df*	*MS*	*F*	$\eta 2$
Learning approaches	820.86	1	820.86	12.23^{**}	0.13
Area	0.61	1	0.61	5.56^{*}	0.063

Learning approaches × Area	372.17	1	372.17	0	0
Error	5489.02	82	66.94		

Note. $^{*}p < .05$; $^{**}p < .01$.

Table 2. Students' learning achievement in the four groups

Area	Learning approaches	Adjusted mean	Std. error.	*N*
Rural	The dual scaffoldings-embedded mobile AR learning	87.01	1.49	43
	The conventional mobile AR-based learning	79.81	1.62	43
Urban	The dual scaffoldings-embedded mobile AR learning	81.78	1.88	43
	The conventional mobile AR-based learning	73.41	2.14	44

As shown in Table 2, it was found that the students in the rural area who utilized the dual scaffolding-embedded mobile AR learning approach (the experimental group; adjusted mean = 87.01) outperformed those who used the conventional mobile AR-based learning approach (the control group; adjusted mean = 79.81). Moreover, for the urban area, the experimental group (adjusted mean = 81.78) also performed better than the control group (adjusted mean = 73.41). Consequently, these results indicated that the students with the dual scaffolding-embedded mobile AR learning approach achieved significantly better learning achievement than those with the conventional mobile AR-based learning approach in rural and urban areas. Furthermore, the rural students who received the intervention of the dual scaffolding-embedded mobile AR learning approach in the experimental group (the experimental group; adjusted mean = 87.01) improved their learning achievement in comparison with those who received the same intervention in the urban area (adjusted mean = 81.78). In this context, it was thought that, compared with the urban area, a dual scaffolding-embedded mobile AR learning approach might influence students' learning achievement more positively in the rural area.

5.2. Higher-order cognition tendency

We performed two-way ANCOVA to analyze the students' perceived higher-order cognition by adopting learning approaches (i.e., the dual scaffolding-embedded mobile AR learning or the conventional mobile AR-based learning) and areas (rural/urban) as independent variables, while the post questionnaire rating of students' perceived higher-order cognition was the dependent variable, and the pre-test degree was the covariate. Levene's test was not significant ($p > .05$), implying that the items for all groups did discriminate usefully. After verifying that the assumption of homogeneity of regression was not violated ($F = 5.34$, $p > .05$), as shown in Table 3, the effect on the relationship between learning approaches and areas was not significant ($p > .05$). However, it was clear that there are significant differences in the dependent variables regarding learning approaches ($F = 10.13$, $p < .01$) and areas ($F = 7.07$, $p < .05$). The ANCOVA result for the experimental group ($\eta2 = 0.101 > 0.059$) and control group ($\eta2 = 0.078 > 0.059$) represented a moderate effect size ($\eta2 = 0.082 > 0.059$). In comparison with the students in the urban area (adjusted mean = 3.72, *SD* = 0.84), it should be noted that those in the rural area (adjusted mean = 4.38, *SD* = 0.89) gave higher ratings for higher-order cognition. Obviously, the students in the dual scaffolding-embedded mobile AR learning approach (adjusted mean = 4.34, *SD* = 0.36) improved their higher-order cognition more significantly than the conventional mobile AR-based learning approach (adjusted mean = 3.78, *SD* = 0.67). These results indicated that the rural area and the dual scaffolding-embedded mobile AR learning approach brought better effects on students' perceived higher-order cognition than the urban area and the conventional mobile AR-based learning approach.

Table 3. ANCOVA results of students' perceived higher-order cognition

Source	*SS*	*df*	*MS*	*F*	$\eta2$
Learning approaches	5.19	1	5.19	10.13^{**}	0.101
Area	3.96	1	3.96	7.07^{*}	0.078
Learning approaches × Area	0.02	1	0.02	0.03	0
Error	47.9	83	0.58		

Note. $^{*}p < .05$; $^{**}p < .01$.

5.3. Self-efficacy

A two-way ANCOVA was used to examine the pre-test data (covariate) to the post-test data (dependent variable). The independent variables in this analysis were learning approaches (i.e., the dual scaffolding-embedded mobile AR learning approach and the conventional mobile AR-based learning approach) and areas (i.e., the rural area and urban area). Prior to the ANCOVA test, Levene's test for self-efficacy was not significant ($p > .05$), which indicated the homogeneity of variance assumption was not violated. The homogeneity was applied to ensure that variances across samples were equal (F = 2.69, p > .05). As presented in Table 4, the analysis of ANCOVA suggested that the main effect of the interaction among learning approaches and area was not significant (p > .05), but the results noted a significant difference among learning approaches (F = 9.26, p < .01, $\eta2$ = 0.095) and areas (F = 4.39, p < .05, $\eta2$ = 0.053). It also revealed that learning approaches have a moderate effect size ($\eta2$ > 0.059). The results indicated that students' self-efficacy in the rural area (adjusted mean = 3.79, SD = 0.71) was significantly higher than that in the urban area (adjusted mean = 3.26, SD = 0.78). This result revealed that learning approaches in the rural area led to a significantly better improvement in students' self-efficacy than in the urban area. The dual scaffolding-embedded mobile AR learning approach (adjusted mean = 4.12, SD = 0.72) outperformed the conventional mobile AR-based learning approach (adjusted mean = 3.51, SD = 0.68). It was found that students who received the dual scaffolding-embedded mobile AR learning approach significantly improved their self-efficacy.

Table 4. ANCOVA results of students' self-efficacy

Source	*SS*	*df*	*MS*	*F*	$\eta2$
Learning approaches	4.56	1	4.56	9.26^{**}	0.095
Area	3.46	1	3.46	4.39^{*}	0.053
Learning approaches × Area	1.47	1	1.47	2.92	0.034
Error	41.7	83	0.5		

Note. $^{*}p$ < .05; $^{**}p$ < .01.

6. Discussion

The current study explored the effect of the dual scaffolding-embedded mobile AR learning approach on students' learning achievement, cognition, and self-efficacy in urban and rural areas. By comparing the achievements of students in urban and rural areas, this study showed that the dual scaffolding-embedded mobile AR learning approach could enhance the achievement of students from both urban and rural areas. This was in line with Hou and Keng (2021), who posited that a multi-dimensional scaffolding-embedded AR learning approach could positively influence students' interaction and learning achievement. The present study further examined the effect of the dual scaffolding-embedded mobile AR learning approach on the higher-order cognition tendency of students from urban and rural areas with three dimensions of complex problem-solving tendency, meta-cognitive awareness, and creativity tendency. The results of higher-order cognition tendency showed the dual scaffolding-embedded mobile AR learning brought better effects than the conventional mobile AR-based learning to mitigate the digital divide between urban and rural settings. This was in good agreement with Ibanez et al. (2016), who found the importance of providing scaffolding for improving students' knowledge construction and cognitive process. Moreover, it was interesting to find that students from rural areas with the dual scaffolding-embedded mobile AR learning approach group had significantly better outcomes than those in the urban area. In other words, it was helpful to mitigate the gap in education outcomes between rural and urban areas with the dual scaffolding-embedded mobile AR learning approach. These findings implied that the dual scaffolding-embedded mobile AR learning approach showed its effectiveness in terms of rural students' learning achievement, higher-order cognition tendency, and self-efficacy, which indicated that it is helpful to mitigate the rural/urban gap in education outcomes with the dual scaffolding-embedded mobile AR learning approach.

For better education outcomes, the interactive situational resources offered by the mobile AR environment should be targeted and pushed to students considering their personalized situations. The study proposed dual scaffolding embedded in the mobile AR environment, which provided matching and guiding schemes to teachers and students with multiple elements instead of only focusing on a single design problem as in existing studies (Hou & Keng, 2021; Tsai & Huang, 2014). For example, although Hou and Keng (2021) investigated predictive factors in dual scaffolding (i.e., peer scaffolding and cognitive scaffolding) for an AR educational board game from students' single perspective, they did not prove the effectiveness of dual scaffolding in an AR learning environment. In contrast to Hou and Keng (2021), this study added value to technology-enhanced scaffolding theory by examining the effects of integrating teacher-student dual scaffolding into AR learning to mitigate the digital divide by promoting both urban and rural students' learning achievement, higher-order cognition, and self-efficacy. Therefore, the study may expand the research on teacher-student scaffolding instruction theory, which advanced understanding of how technology promotes the development of educational science and responded to the lack of effective scaffolding in the current AR education. For example, although Kim and Hannafin (2011) concluded the implication of scaffolding for problem-solving inquiry in technology-enhanced classrooms, given the many dimensions of scaffolding: peer scaffolding, teacher scaffolding, and technology-enhanced scaffolding dimensions, they neglected the value of teacher and student scaffolding. In this regard, the current research is one of the pioneering studies to mitigate the urban-rural digital divide by adopting the dual scaffolding-embedded mobile AR learning approach.

High-quality AR resources should match the application level of teaching scaffolding to promote the equity of education outcomes. However, Li et al. (2020) revealed that it was difficult to provide education resources (e.g., qualified rural teachers and training approaches) based on the rural schools' and teachers' needs. Therefore, we conducted an efficient dual scaffolding-embedded AR learning approach for teachers and students in a mobile AR environment. Unlike previous studies (Hou & Keng, 2021; Lin et al., 2020; Shin et al., 2020) which only considered a single form of scaffolding for teachers or students in the learning process, this study has important practical implications for revealing the role of combining AR with dual scaffolding to mitigate the urban-rural digital divide. For example, although Shin et al. (2020) revealed the role of hard, peer, and teacher scaffolding in technology-enhanced learning, they focused on using teacher scaffolding to enhance students' academic achievement and group performance rather than promoting teachers' teaching effect. This study showed that students in the rural area benefited more greatly than those in the urban area from the dual scaffolding-embedded mobile AR learning approach in terms of their learning achievement, higher-order cognition, and self-efficacy. Accordingly, this study could contribute to providing educational policymakers and school administrators with concrete evidence of how to mitigate the urban-rural digital divide with higher quality and lower cost by incorporating the mobile AR learning approach with the support of teacher-student dual scaffolding in the urban area. In contrast to Lin's et al. (2020) finding that technology-assisted teacher support and reflective scaffolding were more helpful for students to experience, reflect, and inquire in AR-based scientific inquiries, this study indicated much higher values for providing both the learning scaffolding on the student-side system operation and the teaching scaffolding service mechanism on the teacher-side operation to help mitigate the urban-rural digital divide with the mobile AR learning environment. The results of the dual-scaffolding matching mechanism between teachers and students were also generated and tested successfully, so the effectiveness of the research conclusions and outcomes were guaranteed.

7. Conclusion

This study aimed at mitigating the urban-rural digital divide by adopting the dual scaffolding-embedded mobile AR learning approach. Specifically, the result showed inconsistencies in the effects of different areas with the dual scaffolding-embedded mobile AR learning approach on the students' learning achievement, cognition, and self-efficacy. This implied that the academic levels, cognitive tendency levels, and self-efficacy levels should be considered when designing or using guiding approaches for helping teachers design teaching activities and students' learning with AR situational interactive resources. In particular, it is important to avoid low-achieving or lower-efficacy students feeling frustrated when they encounter difficulties in the process of completing the interactive tasks with AR situational interactive resources. Therefore, it is suggested that future studies should analyze students' learning behaviors with different cognitive tendency levels and self-efficacy levels to understand their cognitive tendency and self-efficacy in an effective scaffolding-embedded mobile AR environment. These practices might mitigate the urban-rural digital divide with effective scaffolding, including teachers' teaching scaffolding and students' learning support in mobile AR learning in the post COVID-19 pandemic. It could provide insights for school administrators to assist teachers' total online teaching and students' self-regulation.

8. Limitations

There were three limitations of the present study that should be noted. First, all measures were self-reported, which did not always report students' truth tendency which might cause conceptions with biases. In future research, it is necessary to use a combination of data collection methods, such as teachers' and students' behaviors collected by the system, and self-reported questionnaires to mitigate the biases. Second, due to the limited nature of the statistical tests, this study only examined the validity of the dual scaffolding-embedded mobile AR learning approach to mitigate the urban-rural digital divide in the post COVID-19 period. However, more nuanced crucial ways in the proposed approach for mitigating the urban-rural digital divide may need further exploration. Given the lack of resources in rural areas, future research could track the proposed approach and investigate the crucial ways influencing the effectiveness of this approach in mitigating the urban-rural digital divide. Third, implementation was for 7 weeks and only examined the effect of the dual scaffolding-embedded mobile AR learning approach on K-12 school students' learning achievement, higher-order cognition tendency, and self-efficacy in science. Future research may conduct relevant experiments on more subjects for a longer period to examine its effectiveness.

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