# Primary School Students' Science Inquiry Learning and Behavior Patterns While Exploring Augmented Reality Science Learning


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**Abstract.** Scientific inquiry has been recognized as an effective instructions ability for learners in science education. The present study aims to explore the behavioral patterns of the science inquiry learning process and the behavior patterns of conception construction in augmented reality (AR) science learning activities for primary school students. An AR-based inquiry learning activity of "Exploring the External Conditions of Seed Germination" was supported, which is an attempt to integrate virtual objects with real situations. Learners utilize the AR based learning materials to accumulate experiences and identify problems while observing and perceiving science concepts. They carry out scientific inquiry based on problems. The scientific inquiry learning can be implemented the following eight-step teaching strategies: constructing environment with AR, revealing misconception under experience, correcting mistakes through AR concepts, obtaining new knowledge by reflection and exploration, establishing the experimental scheme with AR, bringing the scheme to completion by modifying, solving scientific questions through AR, making progress under self-reflection. Students' learning behaviors were analyzed by adopting behavioral sequence analysis. The results suggest that the eight-step teaching strategies may support learners' inquiry learning processes to achieve a positive outcome for their self-efficacy in science inquiry learning.



**Keywords:** Augmented reality · Sequential analysis · Science education · Scientific inquiry · Behavioral pattern · Self-efficacy



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# 1 Introduction

Some conception in science education is nonobjective and microscopic views, which make students result in misconceptions in the process of science learning. AR technology presents students with a microscopic scientific environment and a virtual model. Students in the classroom transform nonobjective concepts into elements of real images and 3D models to enhance their conceptual learning and spatial cognition. It has been reported in the literature that there is growing demand for making use of AR to solve the problem of misconceptions in science education. According to Linder, Rienow and Jürgens's study of the designed App "The Earth-Moon System" [1], an empirical study was conducted by AR, which involved the effects of changing in the distance between Earth and Moon as well as a 3D animation between two celestial bodies. The results revealed that it was usable to apply AR to help understanding complex topics. Mustafa and Cakmak [2] implemented an AR application called AtomAR in astronomy, which was one of the difficult science subjects for students to learn at a concepts level. Their study certificated that AR made positive contributions to the misconceptions of students, without affecting their course engagement. These studies enlighten our study to pay more attention to the complex science subjects which impossible for most learners to learn by observing or making an intervention. In order to ensure that students can deeply understand as well as apply the concepts and knowledge to practice, the teaching process is required a combination of various forms of teaching, such as theory, practice and discussion. Another study proposed to combine field experience and the use of information technology to create a problem-based learning environment (Simmons, Wu, Knight and Lopez) [3]. According to this literature, our study found that learners can participate in real scientific inquiry in such an environment supported by AR.

# 2 Literature Review

## 2.1 Research on the Practice of Science Inquiry Learning Supported by AR

Science inquiry learning supported by AR is defined as an instruction to use AR for solving difficult teaching problems, such as explaining nonobjective knowledge, observing the micro world, conducting experiments in a virtual simulation environment, etc. Behmke's study [4] adopted the AR molecule applications at the end of a conventional three-dimensional chemistry teaching. He indicated that AR technology greatly enhanced the experimental group students' enthusiasm to assist them more clearly to describe the three-dimensional structure of the molecule. Duan, Ni, Wu, Fang and Zhang [5] designed AR physics experiment autonomous environment when students learned physics experiment instruments. A majority of students who used the instrument were satisfied with the learning outcomes. Chiang, Yang and Hwang [6] allowed students to use AR scanning for inquiry-based learning while studying aquatic plants. The students were divided into the experimental group and the control group, while the former one held a higher level of knowledge construction. Wu, Hwang, Yang and Chen [7] used AR learning system which based on a database to facilitate students' construction to enable students to learn insect knowledge. As a result, students' knowledge construction and academic performance will be better than with traditional AR learning systems. Cai, Wang and Chiang [8] implemented AR simulation system in a chemistry class, and concluded that the AR inquiry-based learning tool prominently contributed to learning effects. In brief, it has been proved that AR plays a crucial role in science inquiry learning.

### 2.2 Research on Science Inquiry Learning Supported by AR Based on Behavior Analysis

In recent years, the use of emerging information technology to conduct experiential learning research has received widespread attention. However, there is still a lack in quantifying the teaching process and evaluating students' learning outcomes. Secondly, it is difficult for educators to define, implement and evaluate student-centered instruction. Analyzing their behavior helps researchers and educators understand two key points. One is the methodology that promote students to master knowledge, another one is the analysis of the ability cultivation from the overall level. The method of behavior analysis might contribute to improve classroom teaching outcome. The general steps for this method are summarized as follow. Firstly, according to the activity process of teaching and learning, the behavior of teachers and students is divided into certain categories. Subsequently, based on classroom teaching video, conversion sampling is carried out to form behavioral data sequence. For example, Chiang, et al. [6] analyzed the various behaviors when students used AR scanning aquatic plants to learn related knowledge. Furthermore, the results showed the degree of knowledge construction and learning concentration. With the help of a series of analyses of behavioral patterns and cognitive attainment, Cheng and Tsai [9] explored how children and parents read the AR book. Moreover, they examined the children's and parents' reading behavioral patterns while they participated in the process of reading the AR book through cluster analysis. Besides, Cheng, et al. [9] proposed that it is benefit for promoting children and parents' communication and transfer of the AR book reading by integrating a prompting guidance in an AR book system.

The purpose of this study is proposed to answer the following research questions:

(1) How many kinds of learning behaviors do students have in AR-based inquiry learning in science courses?
(2) Are there different sequential patterns of interaction for different kinds of learning behaviors while exploring AR-based inquiry augmented reality science learning?

## 3 Design and Methods

### 3.1 Participants and Procedures

Eight fourth-grade or fifth-grade students (2 male; 6 female) with an average age of 11 years were recruited from Guangdong, Southern China. They were invited randomly to take part in this study. According to a short interview before the study, all of them had experience of using smart phones but less of using AR.

This study mainly validated the feasibility of the strategy through classroom experiments and optimized eight-step teaching strategy based on AR. The study lasted for a period of 8 weeks, involving two 45-m lessons per week. Participants were randomly divided into two groups for collaborative learning. During the class, we use two cameras to record students' learning behavior.

In this case study, each lesson was divided into seven stages: the pre-class introduction stage (CU) - the AR observing stage (CU, PW) - the teacher explaining stage (HCS, CU) - the new knowledge consolidating stage (HCS, PW) – the experimental designing with AR stage (PW, HCS, SC) – the experimental verification with AR stage (PW, HCS, SC) - the knowledge summary stage (EA). The content of the lecture was based on the AR materials, from the growth of seeds to the internal structure of plant cells.

### 3.2 The AR-Based Learning System

In the article "the scientific education application of AR experiential teaching resources: strategies and cases", Lin, Zhu, Wu, Shen and Wang (2019) [10] mentioned the eight-step innovative teaching strategy of AR supported experiential learning, which is constructing environment with AR, revealing misconception under experience, correcting mistakes through AR concepts, obtaining new knowledge by reflection and exploration, establishing the experimental scheme with AR, bringing the scheme to completion by modifying, solving scientific questions through AR, making progress under self-reflection. Under the guidance of the eight-step innovative teaching strategy, this study took "exploring the external conditions of seed germination" as a case to implement the teaching design. In this way, five aspects in science learning was implemented based on the eight-step innovative teaching strategy of AR: Conceptual Understanding (CU), Practical Work (PW), Higher-Order Cognitive Skills (HCS), Science Communication (SC) and Everyday Application (EA). For example, during the process of establishing the experimental scheme with AR to bring the scheme to completion by modifying. Students worked in groups to explore the process of photosynthesis. Students experienced a series of learning activities, for example, they wrote experiment plans, made mutual evaluation and applied AR equipment to carry out experiment plans. At that time, Students' self-efficacy was improved in the following aspects, namely, Practical Work (PW), Higher-Order Cognitive Skills (HCS) and Scientific Communication (SC). Based on the guidance of questions, learners firstly mastered the writing steps of the experimental scheme from "the willow experiment of Helmont". At the same time, questions were raised about the conclusion of the experiment – it was proposed that the weight gain of willow trees may also come from other materials, such as the process of photosynthesis, the generation of oxygen and organic matter by carbon dioxide and water under certain conditions of light, etc., and a point of which was questioned was studied in the group experiment design. For example, to explore whether photosynthesis produces organic or not, the team worked together to design the geranium experiment with the help of the teacher. First of all, the principle was defined. Organic starch was produced by photosynthesis. Starch solution reacted with iodine solution to turn blue. Then, photosynthetic products from the geranium were obtained and tested for starch according to the principle. At this time, two problems were easily ignored in experimental design: one was the photosynthetic products which produced by plants before experiments must be completely consumed, the other was the pigment of the leaves had an effect on the observation. As for these two problems, teachers who acted as facilitators would provide material to assist students in designing the experiment. Students will be instructed to leave the plants in the dark for 24 h and soak the leaves in a water bath heated with alcohol to remove pigment. After the experimental scheme of the group is defined, different modes were selected to implement the experimental scheme by using AR resources for experimental verification, and the key points and difficulties in the experimental process were consolidated and summarized by making use of matters needing attention to compete with each other in games.

Throughout the whole process, students corrected the misconceptions of the seed germination need lighting, and correctly differentiated the seed germination and plant growth. Through the participation of learners in each teaching stage, this study documented all of the valid behaviors that students had performed in the five aspects of science learning (CU, PW, HCS, SC, EA) and encoded them. After that, through behavioral clustering of coding behaviors, we summarized the different behaviors what students would perform at each stage of scientific learning, and then improved the eight-step teaching strategy (Fig. 1).

### 3.3 The AR-Based Learning Material

AR material was implemented in the whole teaching process, including learning observation, experimental verification, experience comparison and so on. In this study, AR resources based on pattern markers are adopted to form the learning manual as shown in Fig. 2 below. In the study of "exploring the external conditions of seed germination", learners can obtain the corresponding AR material on the mobile terminal by scanning the AR logo on the manual. The learning framework, such as the mode, time and guidance of each teaching activity, is clearly presented in the study manual, which can be used as auxiliary teaching materials for classroom teaching. Learners can also scan the QR code of the expanded reading module after class to obtain online learning resources for expanding reading, reviewing and consolidating the knowledge.

### 3.4 Data Collection and Analysis

The data analysis consisted of two steps: cluster analysis to analyze the students' behavioral clustering in each stage and Lag Sequence Analysis (LSA) to organize the conversion relationship between various behavior sets from the previous analysis. The behavioral coding schemes of this study was used to collect students' behavioral data in class for cluster analysis and difference comparison. In terms of content, we combed out the students' behaviors which were observed in the process of teaching practice by combining our own teaching design and the extended eight-step teaching method. In terms of the framework, we adapted the behavior coding schemes from Liu's [11]

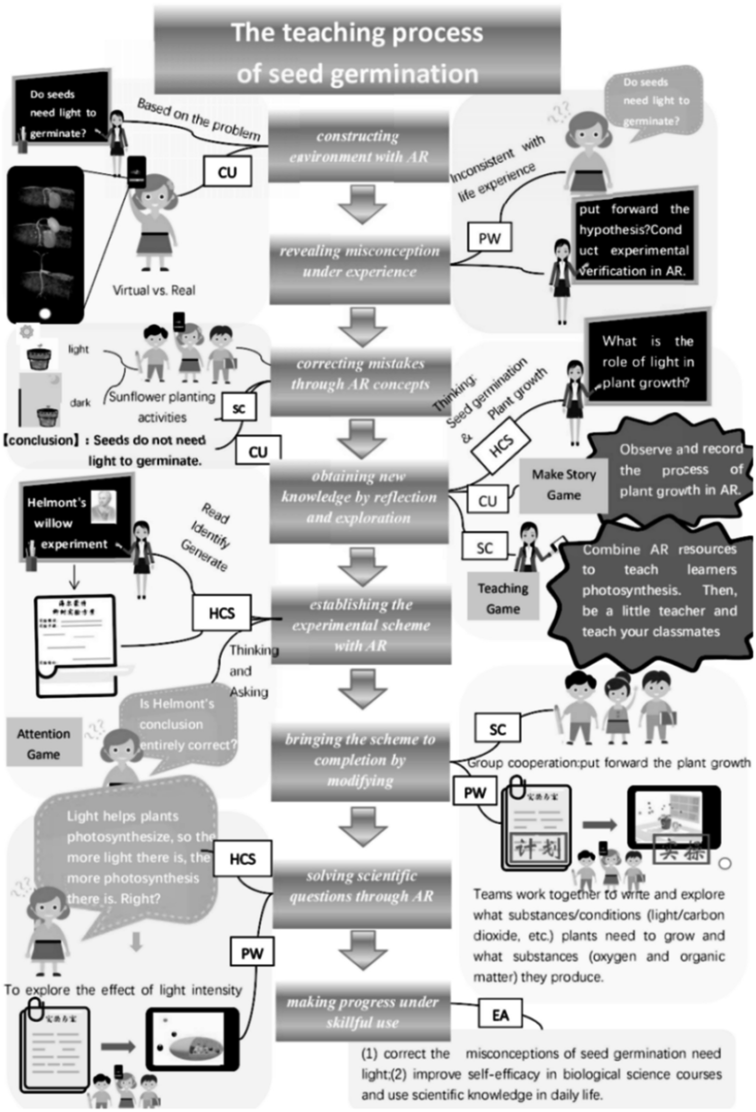


**Fig. 1.** A flowchart of experimental teaching activities of seed germination. Note: Conceptual Understanding (CU), Practical Work (PW), Higher-Order Cognitive Skills (HCS), Science Communication (SC) and Everyday Application (EA).

analysis coding of classroom interaction behavior. The original coding method belonged to the field of educational information technology. It was applied to encode the interaction between teachers and students based on learning activities, which had been recorded into the video. In this study, the coding method was refined and modified into a new coding form. As shown in Table 1, the codes were divided into 12 measurement dimensions, and 14 items were specifically recorded.

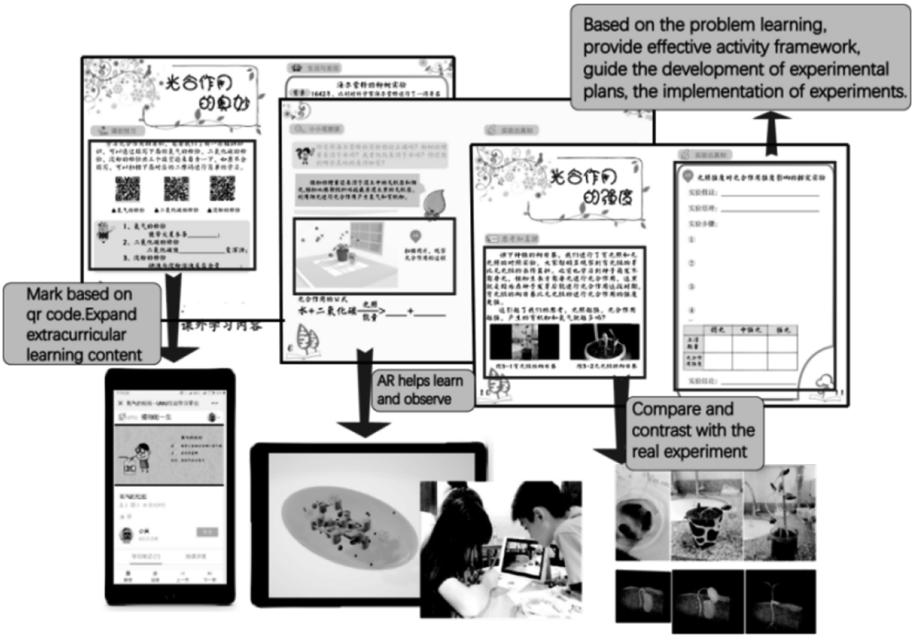


**Fig. 2.** A learning manual of using mark-based AR in learning activities

**Table 1.** The coding schemes for science inquiry learning behaviors.

| Interaction | | Behavior | | Code |
|---|---|---|---|---|
| The interaction between students and teachers | Students' initiative behavior | Put question | | 1 |
| | | Reading and recording | | 2 |
| | Students' passive behavior | Observing | | 3 |
| | | Answering | | 4 |
| | | Practicing | | 5 |
| | | Showing | | 6 |
| The interaction between students | | Discussing | | 7 |
| | | Cooperating (Using AR resources together with peers) | | 8 |
| | | Experiment | Assuming | 9 |
| | | | Exploring | 10 |
| | | | verifying | 11 |
| Student alone | | Operating (Using AR resources along) | | 12 |
| | | Thinking | | 13 |
| | | Distracting | | 14 |

On basis of the coding form, a code was recorded for each change in the student's behaviors and finally a total of 3204 codes was coded. In the end of cluster analysis, five classifications were sorted out from the codes of students' behavior. For describing the clustering results, a framework consisting of five activities to classify students' understanding of scientific concepts proposed by Zhang and Scardamalia [12] was adapted as another new coding scheme: (1) Non-scientific; (2) Pre-scientific; (3) Hybrid/Mixed; (4) Basically scientific; (5) Scientific. The codes used, the description of codes, and the corresponding students' behaviors are presented in Table 2.

**Table 2.** The coding schemes for AR assisted science-related conceptual development behaviors.

| Codes | Description | Behaviors |
|---|---|---|
| Non-scientific (N) | Student does not address the question, instead expressing emotion or chatting to other students | Distracting, chatting to other students |
| Pre-scientific (P) | Student responds to the question naively or based on personal experience | Answering, thinking |
| Hybrid/Mixed (H) | Student responds to the question with others help | Practicing, cooperating, assuming |
| Basically scientific (B) | Student responds to the questions using scientific knowledge but without examples or explanation | Reading and recording, presentation, observing |
| Scientific (S) | The student draws on Previous discussion and scientific concepts to suggest an explanation or hypothesis that may help resolve the question or problem under consideration in experiment with teachers' help | Exploring, verifying, asking question, practicing, discussing |

Then, the researchers took secondary coding of student behavior according to the new coding table. And 763 code strings which were coded based on their chronological order were analyzed to calculate the frequency of each behavioral code following another one. Finally, the analysis tool PuliPuli was used to process the code-strings data for LSA.

## 4 Results

This study focus on analyzing the learning behavior of students in the AR-based experiential science classroom scenario. In the process of scientific inquiry, students often have two or more behaviors that appear repeatedly. For example, in the conceptual understanding of "exploring the external conditions of seed germination", students are often accompanied by several behaviors such as "observing", "reading" and "recording". Therefore, in the experiment, we collected and organized the students' behaviors, trying to help us modify and perfect the eight-step teaching strategy by analyzing the students' behavioral clustering.

As is described in Table 2, five clusters were identified. Behaviors in cluster 1 were distraction. Cluster 2 consisted of answering and thinking. Cluster 3 were practice, cooperation and assuming. Cluster 4 consisted of reading, display and observation. And Cluster 5 were inquiry, verification, questioning, operation and discussion.

With the help of this classification, we re-encoded the process of our teaching, following the principle of recording once the action changes, and setting the five codes to N, P, H, B, and S, corresponding to the five stages in Table 2. In order to investigate the behavioral patterns of AR-based science inquiry learning in depth so as to answer the second research question, a series of LSA were conducted. The results indicates that six sequences reached statistically significant difference ($p < 0.05$). As is illustrated in Fig. 3, six significant sequences were emerged in students' AR Science Inquiry Learning: N → B, B → N, B → P, P → B, H → S, S → B. In the diagrams, the arrow indicates the direction of the behavior transfer for each sequence, while the thickness of the arrow represents the strength of transition probability and the values above the arrow shows Z-value of each sequence.

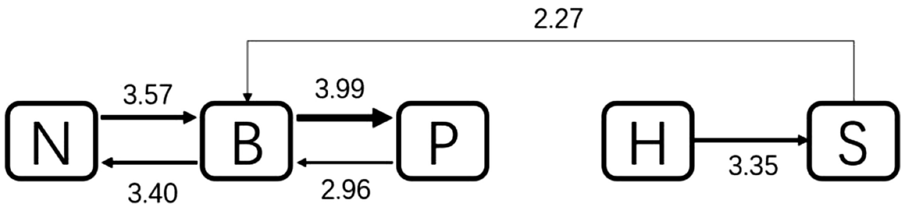


**Fig. 3.** Sequential behavioral patterns of students' AR Science Inquiry Learning.

## 5 Discussion

The first purpose of this study was to investigate the framework of students' learning behaviors in AR-based science inquiry learning. The results indicated that under the AR-supported experiential teaching strategy, the behaviors of the students in the seven stages of instructional design are not significantly different, which indicated that the seven different stages of teaching had similar effects on students' learning behaviors. During the teaching process, the students' "observation" behaviors predominated over other behaviors, while the frequency of "exploration" and "validation" behaviors were relatively low, occurring only once in every two lessons. There were two reasons for observation becoming the most frequent behaviors. For one reason, Chiang and Hwang's research adopted that [13] the AR-based flipped learning guiding approach can play a beneficial role in the students' promotion of their project performance. Moreover, students' learning motivation, critical thinking tendency and group self-efficacy could be improved in the process. Therefore, in the instructional design, was students were requited to discover different phenomena in AR resources and common sense of life through "observation" as well as to ask questions in their earlier stage of learning. For another reason, when the students used AR resources to practice and scientific inquiry, they "observed" the phenomenon, found mistakes and corrected mistakes. At the same time, the reasons for the less occurrence of "exploration" and "validation" due to the fact that the courses on these behaviors were concentrated in the last four lessons, and each inquiry was scheduled for at most one inquiry experiment. Besides, the scientific inquiry activity is a process of continuity and the need for more behaviors such as observation, thinking, hypothesis and operation. As a result, the students' "exploration" and "validation" behaviors only occurred once or twice conforming to the predictions of experimental studies. In addition, the "distraction" behavior occurred frequently. By reviewing the classroom observations and records, the main reason for the students' distraction was that students pay too much attention to the AR resources and neglect the teacher's teaching. In the process of cooperation, some students were not actively involved in the cooperation, instead of waiting for the team members to get the answer.

Further through cluster analysis, this study found that the clustering results of students' learning behaviors are basically consistent with the prediction results of the experiential teaching strategies supported by AR (>50%). The five behaviors of inquiry, verification, questioning, operation and discussion of students are concentrated, which shows that it is correct and effective to use AR resources and teacher guidance to assist students in group cooperation in instructional design. The two categories of "answer and think", "practice, cooperation and hypothesis" can also correspond to the two steps of "AR creation scenario and problem discovery" and "use AR design experiment phase" in the teaching phase. For the categories of "reading, showing and observing", it can be attributed to the fact that when the students are grouped, when the experimental results are displayed, the behaviors of comparing the results and answers between the groups frequently appear. From these results, the proposed AR eight-step teaching strategies do have a positive correlation with students' science learning.

In order to answer the second research question, the students' behavioral patterns of AR-based science inquiry learning were revealed through lag sequence analysis. By using LSA, there were five important behavioral patterns in the whole teaching process. As was recommended by Lin, Duh, Li, H. Wang and Tsai [14], the AR system can be used as a supporting tool to enable dual learners to respond quickly to the displayed results and promote their knowledge building process to produce favorable learning effects. Therefore, we believe that the change of $H \rightarrow S$ ($Z = 3.35$) belongs to the natural phenomenon after the construction of students' knowledge, which shows that AR technology can indeed provide greater help in improving students' ability to learn scientific knowledge. The transformation of $P \rightarrow B$, $S \rightarrow B$ ($Z = 2.96, 2.27$) is mainly related to instructional design. $P \rightarrow B$ corresponds to the first four steps of AR teaching design focusing on students' independent knowledge learning, and $S \rightarrow B$ corresponds to the last four steps of constructive improvement.

In summary, when conducting science teaching using AR technology, special attention should be paid to the transition between knowledge points and how to prevent students' attention from being over-dispersed by the new element of AR technology. The influence of AR technology on science teaching is mainly concentrated in the stage of pre-school preparation and preliminary study, which makes it is necessary to pay attention to the teaching design. This study examined that the design of the teaching link for experimental inquiry could be improved. Students should be guided to conduct of pre-school preparation and preliminary study, which makes it is necessary to pay attention to the teaching design. This effectively improve students' collaborative inquiry ability.

## 6 Conclusion

In this study, a teaching approach supported by AR eight-step teaching strategies was conducted to improve the teaching design of scientific inquiry learning of misconceptions of "necessity and sufficiency of seed generation". In these cases, behavioral analysis can clearly highlight students' behavioral characteristics. Therefore, this study mainly collects students' behavior from three aspects: the interaction between students, the interaction between students and teachers and student personal behaviors. The classroom teaching is carried out under the policy to support innovative teaching in the thirteen specific AR-based step behaviors, including questioning, observing, answering, practicing, displaying, discussing, collaborating, doing experiment assumptions, exploring, verifying operation learn resources and thinking. To sum up, two major contributions and suggestions of this study are proposed for further study: (1) in the student-centered AR experiential teaching process, the role of teachers' instructor and assistant should be noted. Instead of divorcing from the classroom, teachers should give clear guidance on students' learning behavior to ensure that students understand how to conduct autonomous and cooperative learning; (2) AR teaching material should be designed to make use of the advantages of AR. Clearing learning guidance in resources can make learners to result in better learning achievements with less effort. Students can get the answers by their own efforts in the process of completing the learning tasks.

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