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Augmented reality worksheets in field trip learning

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ABSTRACT
Worksheets are often used during field trips and utilize a learning cycle with three stages (exploration, concept introduction and concept application) to engage learners in the learning activities of observation and exploration. However, traditional paper worksheets do not provide multimedia and interactive presentations with physical objects, which made learners losing interaction with the physical context during field trips and failing to implement all the stages completely. This study designed an augmented reality worksheet with a three-stage learning cycle and applied it to learning about plants, specifically assisting learners in observing and classifying plants. A pretest-posttest quasi-experimental design was used to show the effect of learning when learners used augmented reality worksheets. Lag sequence analysis was used to identify learning behavioral patterns. The findings indicate that the learning effect of using augmented reality worksheets is much better than that of paper worksheets and improves the learners' interaction with plants.

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Augmented reality; worksheets; guided discovery learning; field trips; learning cycle

1. Introduction

Worksheets have been applied in various learning activities in recent years (Amalia et al., 2018; Behrendt & Franklin, 2014; Garnier et al., 2017; Sujarittham et al., 2016; Suyidno et al., 2016), specially being as learning tools to guide students in field observation and exploration (Behrendt & Franklin, 2014; Kisiel, 2003, 2007; Thomas et al., 2015). However, the format of paper worksheets comprises words and writing, does not differ from students' experience in a traditional class and reduces students' interest in learning (Delyana et al., 2018; Kisiel, 2003, 2007; Thomas et al., 2015). Furthermore, students cannot confirm whether their answers are correct and cannot correct them after the worksheets have been completed; this affects the learning outcome. In addition, most students cannot receive individual feedback after turning in worksheets, and teachers cannot guide students to the moment of learning, which may also affect the learning outcome (Leslie-Pelecky, 2000). In addition to lacking individual feedback, prior knowledge is needed to help learning when students answer questions on worksheets (Falk & Adelman, 2003; Falk & Storksdieck, 2005; Kisiel, 2003; Mortensen & Smart, 2007). Students cannot obtain a deep understanding through observation and exploration unconnected with an academic background of prior knowledge (Eberbach & Crowley, 2009; Roschelle, 1995). Thus, the use of worksheets as learning tools is subject to the limitations of the paper presentation format, and learners cannot obtain immediate feedback and be reminded of prior knowledge while answering questions in worksheets.

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The design of worksheets is based on a guided discovery learning strategy that implements hints about the questions on the worksheets to guide students to learn (Douglas & Chiu, 2013; Farrell et al., 1999; Sujarittham et al., 2016). The most typical guided discovery learning strategy is a learning cycle with three stages (Abraham & Renner, 1986; Hanuscin & Lee, 2008; Karplus & Butts, 1977; Lawson, 1995; Renner, 1985). The three stages are exploration, concept introduction and concept application. In the exploration stage, learners first identify the learning target according to hints in guided questions, answer questions by exploring the features of the target and discover possible new concepts. In the concept introduction stage, learners review the records of answered questions and refer to supplementary materials about the learning target to clarify the definitions of new concepts. In the concept application stage, learners apply definitions of new concepts to other scenarios that can consolidate such new concepts. The three-stage learning cycle has been implemented as guided inquiry worksheets (Farrell et al., 1999; Palennari et al., 2019), but the two stages of concept introduction and concept application could not be easily performed in a paper worksheet.

In the concept introduction stage, paper worksheets lack records for reviewing new concepts, which makes it difficult to clarify the definitions of new concepts. During this stage, supplementary materials on a paper worksheet cannot be presented in a multimedia format; this impedes understanding new concepts. Thus, paper worksheets make it more difficult to establish the definitions of new concepts, and such concepts cannot be applied to other scenarios, which makes it difficult to achieve the objectives of the concept application stage. Summarily, paper worksheets lack the record of answers for guided questions and supplementary multimedia materials for targets observed and explored in the concept introduction stage.

To implement the learning cycle completely, augmented reality (AR) on mobile devices can potentially be used. The mobile AR has the features of virtual-real superposition, multimedia representation, and immersion and contextualization to overcome the limitations of paper worksheets and strengthen the activities in the learning cycle. AR is also a useful tool for connecting the physical object and the virtual information and has a function in connecting the physical targets with the worksheet knowledge and letting learners have a more immersive experience (Zak, 2014). Moreover, during the activities in the learning cycle, real-time guidance is a vital part that can affect the quality of the learning experience. AR can detect the learning targets and give the corresponding supplementary materials in time. This is impossible with other multimedia technologies, but augmented reality can be easily achieved.

Augmented reality can overlay additional information on the physical targets to be observed or learned (Azuma et al., 2001; Wasko, 2013; Wei et al., 2015; Zak, 2014). AR is implemented via a mobile device to help learners experience contextual interaction and to effectively draw learners' attention to targets in the learning environment (FitzGerald et al., 2013; Ghouaiel et al., 2017). AR technology has been widely applied in education in recent years and has had an effect on learning outcomes in addition to raising motivation (Akçayır & Akçayır, 2017; Bacca et al., 2014; Chang et al., 2014, 2015, 2019; Chao et al., 2014, 2016; Cheng & Tsai, 2013; Gottlieb, 2018; Hsiao et al., 2012; Ibáñez & Delgado-Kloos, 2018; Orman et al., 2017; Radu, 2014; Tom Dieck & Jung, 2018; Wu et al., 2013; Yoon & Wang, 2014; Zhang et al., 2014, 2015, September, 2016, September; Zhang & Chang, 2019, July).

AR-technology has been widely applied in field trip learning (Bursztyn et al., 2017; Huang et al., 2016; Kamarainen et al., 2013). For example, Moorhouse and Jung (2017) aimed to assess how utilizing new and innovative technologies enhance the overall learning experience in the cultural heritage tourism context. Zimmerman and Land (2014) advocated for place-based education to guide research and design for mobile computers used in informal outdoor environments. These studies showed the potential value of integrating AR with the learning cycle. However, in these AR applications, worksheets were not incorporated into field trips. Because a well-designed worksheet provides an effective learning tool in field trips, this study proposes an AR worksheet for field trip learning in a botanical garden where students can observe plants.

The teaching method of a field trip in a botanical garden mostly relies on the presentation of guiding labels or descriptions by docents who provide information on plants. Guiding labels are limited to their dimensions and can only provide limited information. Docents can merely talk about plants and experience difficulties describing them. It is so difficult for either presentation to build the interaction between plants and learners that efficient learning becomes impossible (Wiegand et al., 2013). The interaction with the physical context in field trips is one of the factors affecting the learning outcome; hence, a design that increases the chances of interaction with the physical context is needed in field trip learning (Lavie Alon & Tal, 2017; Tal et al., 2014). AR-assisted learning has been proven to increase the interactions among learner, mobile device, and physical context (Chang et al., 2014, 2015; Sung et al., 2010, 2016). This study applies AR technology to implement worksheets with the learning cycle strategy to enhance learning outcomes and increase the chances of interaction with the physical context.

The paper verifies the learning achievements and analyzes the behavioral patterns of learners who interact with mobile devices and plants in botanical garden. A pretest-posttest quasi-experimental design was used to demonstrate the effect of learning. It showed that the learning effect of the use of AR worksheets was much better than that of the paper worksheets. Lag sequence analysis (Hou et al., 2010a, 2010b, 2011a, 2011b; Sung et al., 2010) was used to identify learning behavioral patterns at the three stages of the learning cycle. The findings indicated that learners who used AR worksheets interacted more with plants.

2. System outline

2.1. Exploration stage

In this stage, students observe and explore the features of plants. Learners use the screen and camera of a mobile device to look for and recognize plants (see Figure 1) and to carefully observe various aspects of plants (such as the type of plant, the epidermis of stems or the features of leaves). The worksheet (see Figure 2) is shown on the screen of the mobile device after plants have been detected. Students answer the guided questions on the worksheet and record the results of their observations.

2.2. Concept introduction stage

In this stage, the AR system provides feedback for the answers to the guided questions from the exploration stage and allows students to correct wrong answers. The top part of Figure 3 presents an example of feedback. A pen is provided next to the wrong answers for students to correct answers. The bottom part of Figure 3 shows the links to the supplementary materials for extended learning. These materials may include content such as inflorescence, applications of plants, and knowledge about plants in specific seasons. The supplementary materials are represented through various media, including a video introduction. To help students structure extended learning, the

Figure 1. Students use a mobile device to observe plants in the learning field.

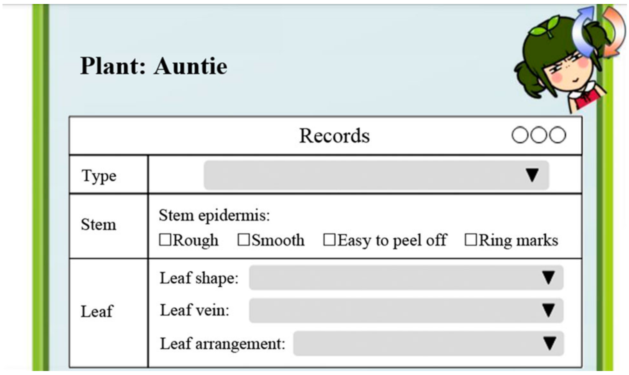

Figure 2. Worksheet shown on an AR mobile device.

last step in this stage allows students to answer questions about the information in the supplementary materials.

2.3. Concept application stage

Learners become familiar with the features of plants via the two previous stages. This stage allows students to return to the botanical garden and match the plants with specific features to apply what they have learned. For example, Figure 4 shows the features of a plant. With these features, students look for the plant in the botanical garden.

3. Experiment

3.1. Experimental design

In this study, we adopted a pretest-posttest quasi-experimental design with an experimental group and a control group. The students in the experimental group used AR worksheets while the control group used paper worksheets. The learning content was the unit on "Recognizing Plants" in a third-grade science course of the elementary school. This study performed an ANCOVA and used a lag sequence analysis to identify the behavioral patterns of learners in these two groups.

The location of this experiment was Taipei Botanical Garden. Both groups in this study operated the devices independently to observe plants. Before the formal experiment, a pretest (20 min) and

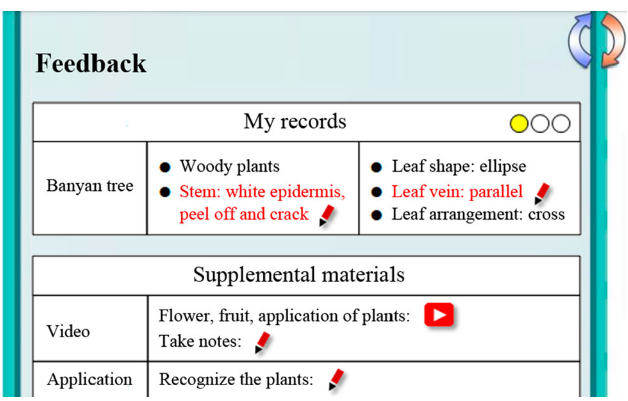

Figure 3. Content of feedback.

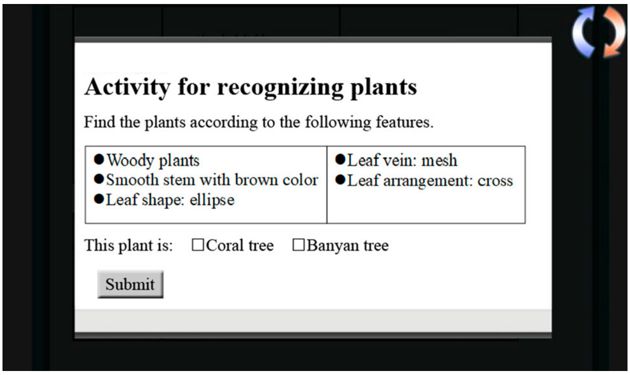

Figure 4. Looking for plants according to features.

experiment instructions (10 min) were provided in the classroom. After the instructions were described, the learning tools were distributed (paper worksheets and mini-cameras for the control group and the mobile device with the AR worksheets and mini-cameras for the experimental group). The control group and the experimental group can receive the same learning content during the experiment. However, due to the limitation of paper worksheets, the control group cannot receive any immediate feedback and "just-in-time" multimedia supplementary materials. Each group began an observation activity and performed one learning cycle for every plant. All learners observe the plant characteristics in the actual environment according to the questions on the worksheets and record their answers on the worksheet. With the help of AR worksheets, the learners in the experimental group use mini-cameras on mobile devices to recognize the target plants. During observing the target plants, the experimental group learners may read the AR-based supplementary teaching material on mobile devices. However, the learners in the control group read the paper-based supplementary teaching material about the plants they are observing. The entire activity took approximately 30 min. Finally, a 20-minute post-test was administered. During the experiment, all groups' learners were allowed to return to the previous learning stages and repeat the learning activities until they were proficient in the content. The three stages in the learning cycle are not performed separately but are integrated into a learning process by the guidance in the worksheets. Since there are not many learning contents, the learning process can be completed within 30 min.

3.2. Participants

The participants were third-grade students (averaging 8 years old) with a basic knowledge of the plants' features but who had never visited the Taipei botanical garden. All participants had considerable experience with mobile phones, but none with AR. The pre-experiment equipment training ensured that the participants could operate the system properly. There were 45 students in the control group and 44 students in the experimental group. All participants were randomly assigned to the experimental group and the control group.

3.3. Tools

3.3.1. Worksheets

The worksheet is designed by a senior teacher who has been a science teacher of elementary school for many years. The content of the paper worksheet and the AR worksheet was the same, and both sheets provided questions with the same answer options. However, the paper worksheet provided all information at once; therefore, this format could not confirm whether the learners completed the observation activities in sequence from the first to the last stage. In addition, learners with paper worksheets did not receive feedback on their records and answers during the observation activity.

3.3.2. Materials

The teaching materials of the study are from the topics of natural science textbooks in third-grade elementary school. The topics are to understand the appearance and features of plants, including the roots, stems, leaves, and other elements of several different plants for students to learn. During the class, we have three stages included to discover and record the characteristics of the plant (exploration stage), read the detailed introduction of the plant (concept introduction), and find other plants with the same characteristics (concept application). The teaching activities based on the materials are designed for 30-minute courses.

3.3.3. Pretest and posttest of plant observation

The objective of pretest and posttest for this experiment was to verify whether the learners were able to increase their understanding of plant classification and to verify their learning outcomes with paper or AR worksheets, respectively. The questions on the tests required students to observe physical plants and which contains more details about what they saw. The tests are the type of multiple choice question and has 20 questions with 100 points in total. The content of the questions of the pretest and the posttest was the same; the two tests only varied the sequence of the question numbers and the answer options. The subjects of the pilot test were third-grade students (47 students in two classes). The results of the analysis showed a Kuder-Richardson reliability of 0.702.

4. Results

4.1. Learning achievement

The means and standard deviations of the pretest and posttest for the two groups are shown in Table 1. Before the analysis of one-way covariance, we performed a test of homogeneity of regression coefficients within groups. The covariate was the score of the pretest, and the dependent variable was the score of the posttest. The result of the test of homogeneity of regression coefficients was not significant, F=2.371 and p=.127 > .05. This result confirmed the hypothesis of homogeneity of the regression coefficient, i.e. we could continue to perform an analysis of covariance.

As shown in Table 2, the influence effects of the pretest on the posttest were F=4.328, p=.040 < .05 and reached significance through an analysis of one-way covariance after ruling out the effects of the scores of pretest (covariate) on the scores of the posttest (dependent variable). The treatment levels of the experiment were significant, indicating that the learning achievement of the experimental group was obviously better to that of the control group.

4.2. Learning behavior

To understand the overall behavioral pattern of students in the two groups during the activity of plant observation and the students' behavioral patterns in each stage of the learning cycle, coding of learning behavior was first performed based on the mini camera's recording, and then a

Table 1. Means and standard deviations for pretest and posttest

		Number	Mean	Standard deviation
Pretest	Control group	44	46.9251	12.00095
	Experimental group	45	46.7974	16.54089
Posttest	Control group	44	47.9947	12.16443
	Experimental group	45	54.1176	19.65413

Table 2. ANCOVA table of the pre-test and post-test.

Dependent Variable: post-test

Source	Type III Sum of Squares	df	Mean Square	*F*	Sig.
Corrected Model	7208.839[a]	2	3604.419	18.251	.000
Intercept	4138.928	1	4138.928	20.957	.000
Pre-test	6374.768	1	6374.768	32.278	.000
Group	854.761	1	854.761	4.328	.040
Error	16984.622	86	197.496		
Total	256505.190	89			
Corrected Total	24193.461	88			

[a]R Squared = .298 (Adjusted R Squared = .282)

lag sequential analysis was applied to the coding. Based on these behavioral patterns, the interaction among learner, mobile device, and physical context during the three stages was analyzed.

The coding of learning behaviors is shown in Table 3. In this table, codes of series A represent the interaction between learners and physical plants, codes of series B represent the interaction between learners and mobile devices, codes of series C represent the interaction between learners and other people, and codes of series D represent other behaviors. The codes are classified according to the time sequence of the video. In addition, behaviors such as B1 (Plant recognition), B4 (Watch instructions of feedback), B5 (Watch a video) and B6 (Log in again/restart) are only applicable to students in the experimental group with AR worksheets. To enhance the reliability of the codes, two coders participated in this experimental activity of the study and performed coding together. They subsequently performed a Kappa consistency analysis, obtaining the values of .676, p=.000 < .05, indicating that the two coders had a remarkably high level of consistency in coding.

Table 4 shows the average count for each behavior of learners in the two groups. The average number of behaviors is counted by the record, which is captured by the head-mounted miniature camera. Through the coding analysis of Table 3, we average the total number of times that each learner in the same group has the same code. Behaviors with higher average counts in the control group were B3 (Record and answer), A3 (Quick plant observation), D1 (Walk and move), C2 (Nonrelevant discussion) and B2 (Watch and describe). Behaviors with higher average counts in the experimental group were B3 (Record and answer), A3 (Quick plant observation) and B4 (Watch instructions of feedback). To analyze the interaction behaviors between learners and physical plants, we added the counts of behaviors with series A coding for the two groups in the table. The total counts of interactions between learners and physical plants were 23.7 in the control group and 27.8 in the experimental group. Thus, the count of interactions with plants for learners in the experimental group was greater than that for the control group. Table 4 also shows that some behaviors (B1, B4, B5, and B6) do not occur in the control group due to the limitation of paper worksheets. Therefore, the behavior patterns related to these behaviors are exhibited in the experimental group, but not in the control group.

Table 3. Coding of learning behaviors

Code	Learning Behavior
A1	Look for plants
A2	Focus on observing plants (focus for more than 5 s)
A3	Quick plant observation (less than 5 s)
A4	Direct interaction with physical plants (such as touching plants)
B1	Plant recognition (Look for the recorded locations of plants)
B2	Watch and describe
B3	Record and answer
B4	Watch instructions of feedback
B5	Watch a video
B6	Log in again/restart
C1	Relevant discussion (discuss plants with peers)
C2	Nonrelevant discussion (chat with peers)
C3	Look for a service provider
D1	Walk and move

Table 4. Average counts of various behaviors for the two groups.

	A1	A2	A3	A4	B1	B2	B3	B4	B5
Control group	1.33	4.71	15.90	1.76		12.83	30.05		
Experimental group	1.75	5.92	18.67	1.46	3.04	0.75	25.63	12.38	5.50
	B6	**C1**	**C2**	**C3**	**D1**				
Control group		7.48	13.24	1.38	13.86				
Experimental group	4.83	5.83	8.71	5.08	10.29				

4.2.1. Behavioral patterns of students in the control group

We added the count of changes in every two behaviors of students in the control group to determine the average count of changes and then converted the average count to Z scores. If Z is greater than 1.96, the change in the two behaviors reaches significance (p<.05). After sorting the behaviors associated with significant changes, a behavioral pattern is established, as shown in Figure 5, where the line thickness indicates the frequency of changes for two behaviors. Higher values of that frequency (corresponding to higher Z values) are represented by thicker linking lines, and the value above the line is the average count of changes for two behaviors. The value in parentheses under each behavior is the average number of occurrences of that behavior.

As shown in Figure 5, the highest frequency of changed behavior was for B2 (Watch and describe) →B3 (Record and answer) and A3 (Quick plant observation) →B3 (Record and answer), and the second highest was for B3 (Record and answer) →A3 (Quick plant observation), B3 (Record and answer) →B2 (Watch and describe) and D1 (Walk and move) →C2 (Nonrelevant discussion) for the learners in the control group. Based on the frequency of each consecutive changing behavior, three such changes were significant: B2 (Watch and describe) →B3 (Record and answer) →B2 (Watch and describe), A3 (Quick plant observation) →B3 (Record and answer) →A3 (Quick plant observation) and D1 (Walk and move) →C2 (Nonrelevant discussion) →D1 (Walk and move).

The beginning behavior for every learner in the control group is D1 (Walk and move). Students walk and move and simultaneously observe surrounding plants along a path. During the process of looking for a plant, learners may need to compare other nearby plants with the target plant's features to find the correct answer. In this process of looking for a plant, learners mostly seek assistance

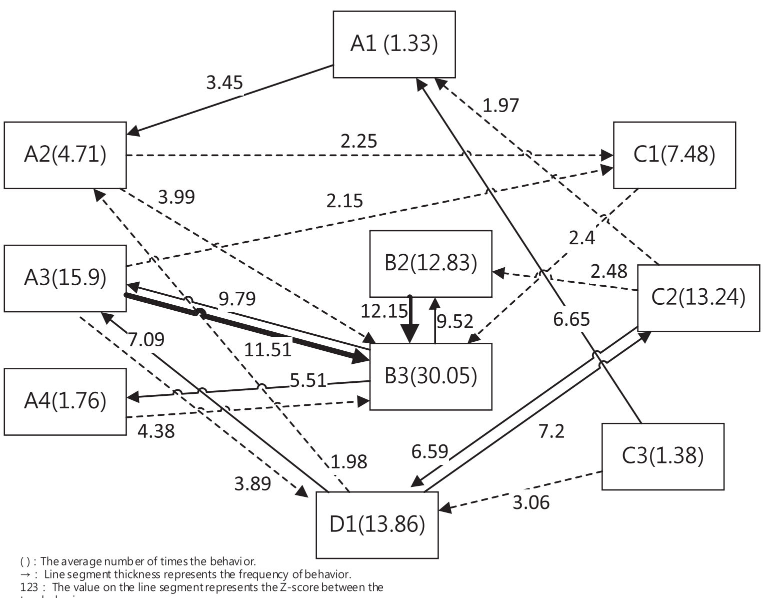

Figure 5. Behavioral patterns of learning in the control group.

from service providers or get help from peers to find a new plant indicated on the worksheet and then focus on observing the plant to confirm the plant's features, record the information about the plant, and answer the questions on the worksheet. After the observation of the plants, learners return to behavior D1 (Walk and move) to start a new observation of the next plant.

4.2.2. Behavioral patterns of students in the experimental group

The changing behaviors of learners in the experimental group are shown in Figure 6. The changing behaviors with the highest frequency are B4 (Watch instructions of feedback) →B5 (Watch a video) and B3 (Record and answer) →A3 (Quick plant observation). Those with the second highest frequency are A3 (Quick plant observation) →B3 (Record and answer), D1 (Walk and move) →B1 (Plant recognition), B3 (Record and answer) →B4 (Watch instructions of feedback), D1 (Walk and move) →A3 (Quick plant observation) and B6 (Log in again/restart) →C3 (Look for a service provider).

Figure 6 shows the three most significant consecutive changing behaviors, B4 (Watch instructions of feedback) →B5 (Watch a video) →B4 (Watch instructions of feedback), B3 (Record and answer) →A3 (Quick plant observation) →B3 (Record and answer) and D1 (Walk and move) →B1 (Plant recognition) →B3 (Record and answer).

As shown in Figure 6, learners walk and move and simultaneously observe surrounding plants and recognize plants with the aid of AR worksheets. After finding the target plant, learners begin recording the plant's observation and discuss the plant with peers. Learners obtain feedback from AR worksheets after they complete the recording. After reading the feedback, learners may choose to watch the video provided by the AR worksheets. In addition, learners may record notes and provide answers on the AR worksheet. Learners mostly obtain help from peers to discover new plants with hints on the AR worksheet during the process of looking for a plant. After completing the observation of a plant, learners begin a new observation activity of the next plant and return to behavior D1 (Walk and move).

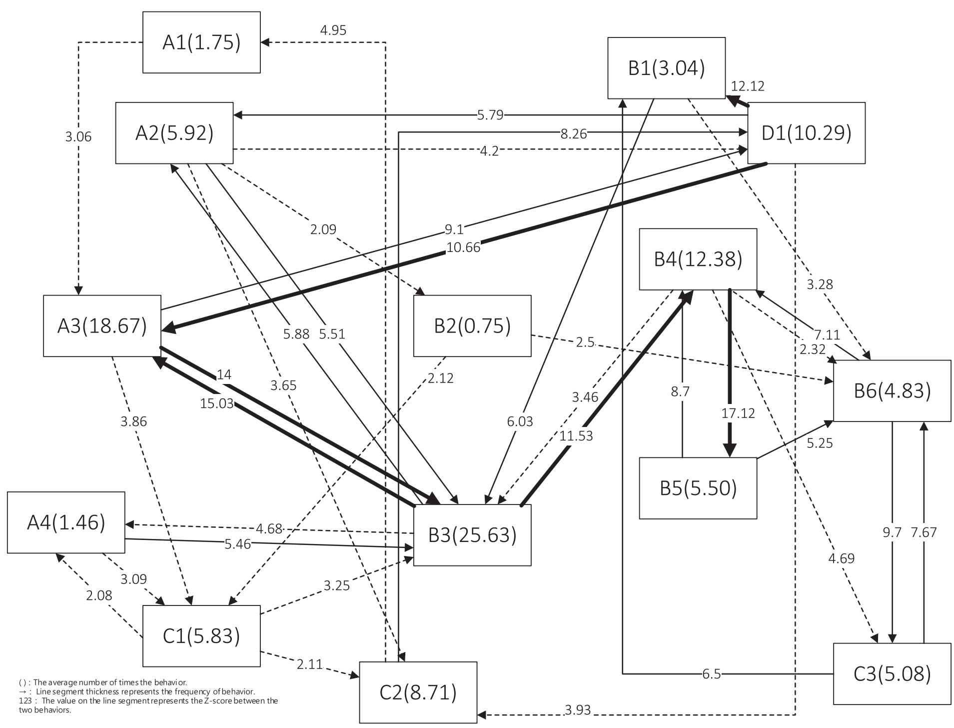

Figure 6. Behavioral patterns of learners in the experimental group.

4.2.3. Behavioral patterns of three stages of the learning cycle

To understand the main behaviors in each stage of the learning cycle, we remove the behaviors that do not exist in that stage and remodel the behavior patterns in the stage. Below are the models of behavioral patterns in the stages of exploration, concept introduction and concept application.

1. Exploration stage. After ruling out the behaviors that occur in the concept introduction and concept application stages, we remodel the behavior patterns in the exploration stage (as shown in Figures 7 and 8 for the two groups). Figure 7 shows that the most significant changing behaviors for learners in the control group in the exploration stage are A3 (Quick plant observation) ↔B3 (Record and answer), D1 (Walk and move) →A3 (Quick plant observation), D1 (Walk and move) ↔C2 (Nonrelevant discussion) and B3 (Record and answer) →A4 (Direct interaction with the physical plants). The average numbers of changes B3→A3 and B3→A4 are 8.24 and 1.24; hence, the average number of observations and explorations of plants in this stage is 9.48.

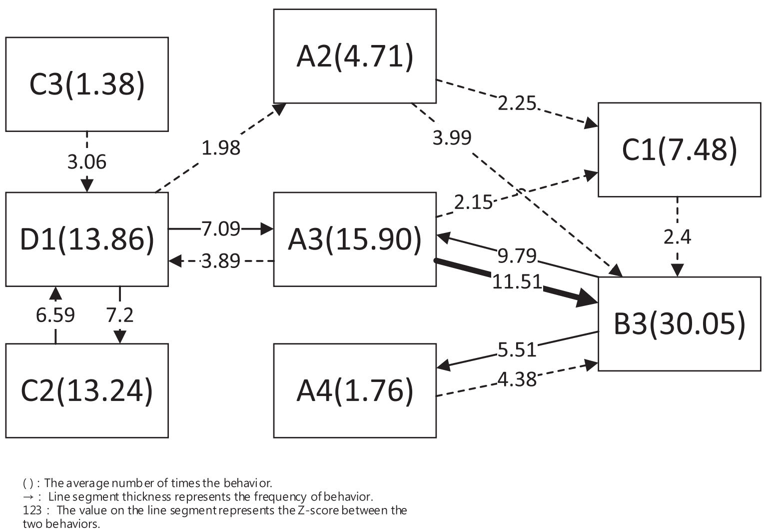

Figure 7. Behavioral patterns of learners in the control group during the exploration stage.

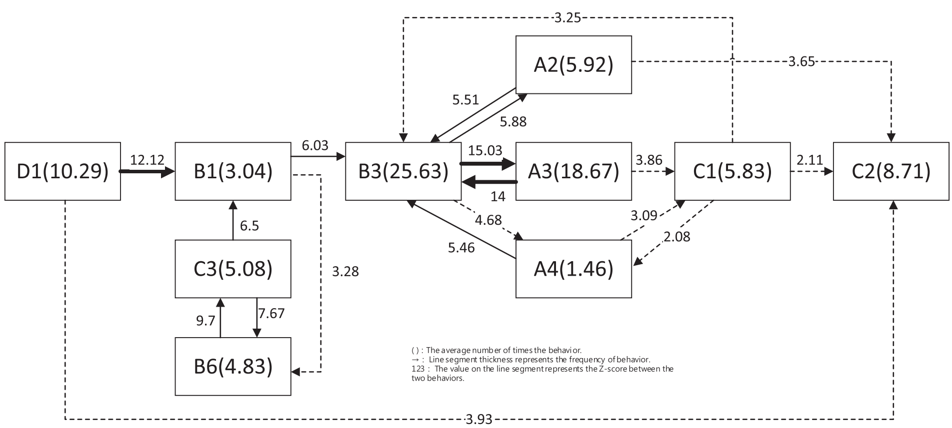

Figure 8. Behavioral patterns of learners in the experimental group during the exploration stage.

As shown in Figure 8, the most significant changing behaviors of learners in the experimental group in the exploration stage are D1 (Walk and move) →B1 (Plant recognition) →B3 (Record and answer), B3 (Record and answer) ↔A3 (Quick plant observation), B3 (Record and answer) ↔A2 (Focus on observing plants), A4 (Direct interaction with the physical plants) →B3 (Record and answer) and C3 (Look for a service provider) →B1 (Plant recognition). The average number of changes B3→A2 is 2.50, B3→A3 is 9.25, and B3→A4 is 0.83. So, the average number of observations and explorations of plants at this stage is 12.58.

The experimental group has two more behaviors than the control group in the exploration stage: B1 (Plant recognition) and B6 (Log in again/restart). The reason for B6 (Log in again/restart) is that students may not be able to find the plant and may need to restart the app and reload the GPS information. However, this only affects a portion of learners and has a comparatively small effect on learning. Most learners can recognize the plant features after the assistance of the service providers.

Comparing the two groups of learners based on the effects from the guided questions and the interactions with physical plants, the experimental group exhibit one more changing behavior of B3 (Record and answer) →A2 (Focus on observing plants) than that the control group; additionally, the average number of 12.58 interactions with physical plants for the experimental group is higher than the 9.48 for the control group. Thus, the experimental group engaged in more instances of plant observation due to the guided questions. Under the same condition with the guided questions, the learners in the experimental group were not led by the device to ignore the physical plants but instead exhibited more observation behaviors than did the learners in the control group and experienced the interactions among learner, mobile device, and physical context.

2. Concept introduction stage. The behavioral patterns of learners in the control group in this stage are shown in Figure 9, indicating that the two main changing behaviors of learners are between B2 (Watch and describe) and B3 (Record and answer). Thus, the learners in this stage give their answers directly based on the supplementary materials of paper worksheets. The learners also engage in less interaction with physical plants in this stage. The reason might be the supplementary materials, which include associated information about various seasons and locations for the observed plants that cannot be checked by directly seeing or interacting with the plants.

The behavioral patterns of learners in the experimental group in this stage are shown in Figure 10, indicating that the most significant changes among the three behaviors of learners are B3 (Record and answer), B4 (Watch instructions of feedback) and B5 (Watch a video). The second most significant are B5 (Watch a video) →B6 (Log in again/restart), B6 (Log in again/restart) →C3 (Look for a service provider) and B6 (Log in again/restart) →B4 (Watch instructions of feedback). In the concept introduction stage, similarly to the control group, learners in the experimental group lack interaction with physical plants. Learners obtain feedback after submitting recordings and answering questions in

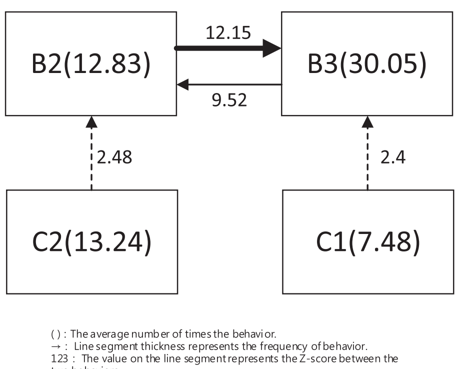

Figure 9. Behavioral patterns of learners in the control group during the concept introduction stage.

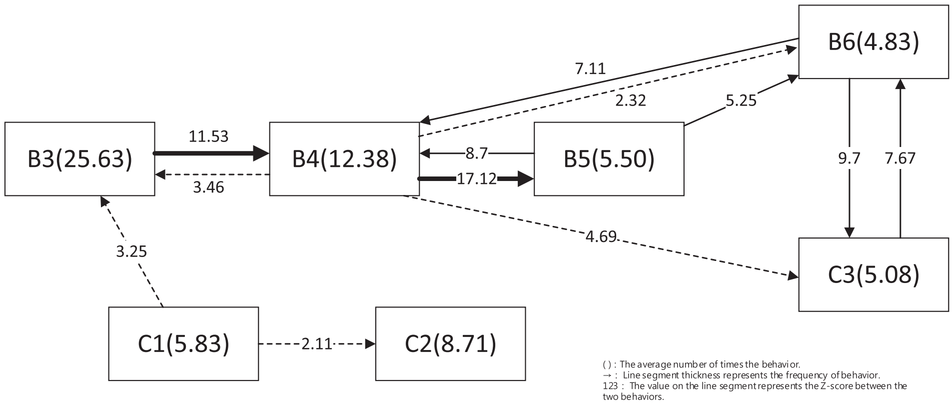

Figure 10. Behavioral patterns of learners in the experimental group during the concept introduction stage.

the preceding exploration stage; therefore, the following behaviors occur between watching the instructions of the feedback and watching a video. The average number of instructions watched for feedback is 12.38, and the average number of videos watched is 5.50.

In the concept introduction stage, three significant behaviors occurred in the experimental group but not in the control group: B4 (Watch instructions of feedback), B6 (Log in again/restart), and C3 (Look for a service provider). In addition, B4 and B5 were the main behaviors that existed only in the experimental group in this stage. There was no behavior of the control group corresponding to B4 (Watch instructions of feedback). Behavior B2 (Watch the supplement) in the control group may be similar to B5 (Watch a video) in the experimental group. Because of the lack of feedback function corresponding to that provided in the AR worksheet, the control group did not fully complete the processes in the learning cycle.

3. Concept application stage. The behavioral patterns of the two groups in the concept application stage are shown in Figures 11 and 12. Learners in the control group seek the locations of plants mostly by looking for service providers or peers; in contrast, the experimental group does so with help from peers. The average number of instances of seeking plants for the control group was 1.33, and that for the experimental group was 1.75. This finding indicates that learners do not complete the learning activity properly in this stage. The possible reasons might be that the guidance on the worksheet is too simple, and the method of recording observations and answering questions is unsuitable, making many learners skip step A1 (Look for plants) and go on to B3 (Record and answer).

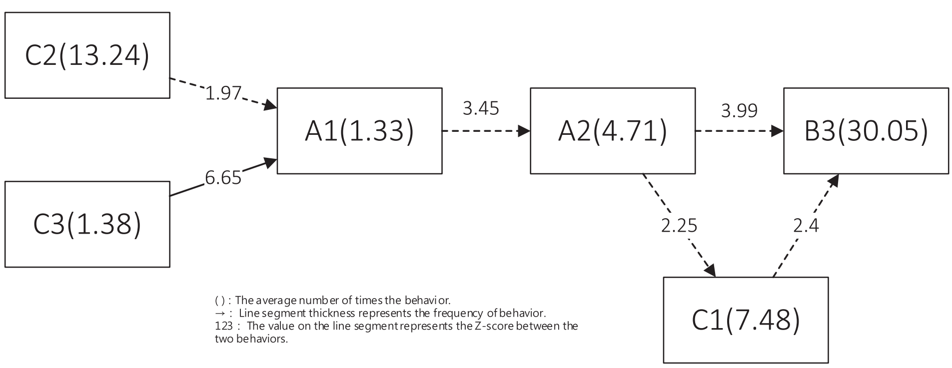

Figure 11. Behavioral patterns of learners in the control group during the concept application stage.

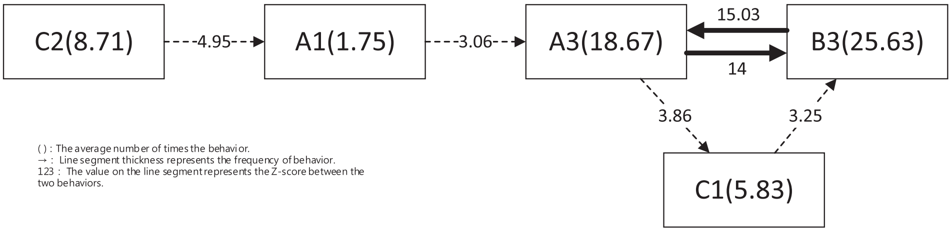

Figure 12. Behavioral patterns of learners in the experimental group during the concept application stage.

There is one more behavior observed in the control group than in the experimental group. The changing behavior of C3 (Look for a service provider) →A1 (Look for plants) reaches significance. The learners in the control group prefer seeking answers from relevant personnel (service providers or peers); in contrast, the learners in the experimental group prefer discussions with peers when answering questions.

5. Discussion

5.1. Learning achievement

Although the control group's students engaged in learning via the stages of exploration, concept introduction, and concept application, the students lacked assistance in establishing new concepts in the concept introduction stage. In other words, students in the experimental group could obtain feedback and review the recorded information in the concept introduction stage, enabling them to organize the knowledge to understand the new concepts and then apply such concepts in the concept application stage. Therefore, the learners in the control group do not fully complete the three-stage learning cycle. In general, field trips using paper worksheets are limited to quota restrictions of instructors, so each learner is unable to receive personalized feedback. Therefore, paper worksheets cannot be fully combined with the learning cycle. Given the above limitation of paper worksheets, the learning achievement of the control group is lower than that of the experimental group. This result also shows that the three-stage learning cycle is implemented fully to realize the effectiveness of guided inquiry worksheets (Farrell et al., 1999; Palennari et al., 2019).

5.2. Interaction with the plants

Based on the analysis of the behavioral patterns of learners in the experimental group, the interactions among learner, mobile device, and physical context in the three stages are as follows. (1) In the exploration stage, the recognition function and guided questions on the AR worksheets allow learners to have more chances for the interaction among learner, mobile device, and physical context. (2) In the concept introduction stage, learners focus on the introduction videos and notes taken in the exploration stage, and thus only have the interaction of learner and mobile device. (3) In the concept application stage, learners need to answer the guided questions on the AR worksheets, so the attention of learners is turned back to the interaction among learner, mobile device, and physical context. As a whole, most learners can balance the ratio of these interactions during the learning activity without ignoring the physical environment. During the learning activity, the average number of interactions of learners with physical plants is 27.8 for the experimental group and 23.7 for the control group, indicating that AR worksheets encourage learners to interact more with physical plants; this finding is similar to the results of previous studies (Chang et al., 2014, 2015; Sung et al., 2010, 2016).

In the exploration stage, the experimental group has a more significant changing behavior B3 (Record and answer) →A2 (Focus on observing plants) than does the control group, showing that the function of guided questions in AR worksheets increases learners' opportunity to focus on observing plants. The interaction between learners and physical plants is not significant at the concept introduction stage; however, the design of the activity of looking for plants at the concept application stage creates an opportunity for learners in the two groups to interact with physical plants. Unfortunately, learners in the two groups do not perform activities well in the concept application stage and do not interact with plants as effectively as during learning in the exploration stage. Behavior A1 (Look for plants) occurs an average of 1.75 times in the experimental group, which is slightly higher than the respective figure for the control group (1.73 times). In summary, the interaction with plants for learners in the experimental group is superior to that of the control group. The assistance of the AR worksheet helps the interaction between the learners and plants.

6. Conclusions

To overcome the limitations of multimedia presentations and the insufficient interactivity of paper worksheets, this study designed AR worksheets with a learning cycle and applied these worksheets to field trips focused on plant observation. The AR worksheets improved learning outcomes more effectively than paper worksheets and also performed better interaction among learner, mobile device, and physical context.

The interaction of plants with AR worksheets in the concept introduction stage is insufficient, and only shows the interaction of learner and mobile device. However, AR worksheets can somewhat facilitate the interaction with the physical learning environment. For example, such worksheets can provide a pause function for video playback and hints to guide learners to observe plants to enhance learners' interaction with plants. In addition, although the interaction among learner, mobile device, and physical context may have occurred in the concept application stage, AR worksheets do not guide students efficiently towards observing plants because the guided questions are too easy, and so, students finish answering those questions without observing the plants. The guiding methods can be diversified to increase the opportunity for physical interaction, such as by adding complicated questions, figures or videos to the questions.

The study concludes that AR effectively strengthens traditional paper worksheets enabling learners to pay more attention to physical targets. AR provides richer multimedia content than paper worksheets alone so that the learning process will not cause learners to ignore physical targets. An effective attempt has been completed in the study. Although many multimedia technologies may be applied to the three-stage learning cycle, the immediacy and connectivity features of AR cannot easily to implement by other technologies.

However, the learning cycle strategy was usually used in worksheets; some much more efficient learning strategies may be explored for AR worksheets. Additionally, it is possible to find some new AR-based learning tools for learning efficiently in field trips since they use worksheets as learning tools.

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