Seamless Connection between Learning and Assessment- Applying Progressive Learning Tasks in Mobile Ecology Inquiry

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ABSTRACT

Mobile learning has been recommended for motivating students on field trips; nevertheless, owing to the complexity and the richness of the learning resources from both the real-world and the digital-world environments, information overload remains one of the major concerns. Most mobile learning designs provide feedback only for multiple choice items to guide students' learning. The aim of this study was to develop a series of worksheets as scaffolding to support inquiry-based ecology observations in a mobile learning environment. Based on a three-layer worksheet framework, a mobile learning system with in-field scoring rubrics was developed to guide the students to sequentially focus on guided observations, independent observations, and extended inquiries. Well-designed worksheets, instant feedback and supplementary materials were provided to balance the students' learning pressure and task challenge in the species-rich field. The automated scoring data for constructed response tasks were analyzed to investigate the learning growth and students' learning characteristics. The results showed that the proposed approach was effective in improving the field observation performance of the students. Furthermore, nearly 70% of the students who learned with the proposed approach could pursue their own inquiries in the mobile learning environment, showing that the approach is promising.

Introduction

In the past decades, the constructivist paradigm has played an important role in educational research. From a constructivist perspective, it is crucial that learners are engaged in constructing their own knowledge in one form or another (Hmelo-Silver, Duncan, & Chinn, 2007; Mayer, 2004; Palincsar, 1998). The practices of scientific inquiry including posing questions, observing in the field, gathering, analyzing and interpreting data, and constructing evidence-based arguments aim to fulfill the objectives of the constructivist process (Kuhn et al., 2000; Krajcik & Blumenfeld, 2006). The purpose of education is to cultivate independent and self-directed learners (Bruner, 1985). However, the free exploration of a highly complex environment may generate a heavy working memory load that is detrimental for novice learners.

Cognitive and psychometric studies on human learning have revealed the potential to greatly influence instructional design principles (Gorin, 2006; Kalyuga, 2009). However, it is conceptually difficult for most teachers to apply effective guided instruction to cultivate self-directed learners by themselves (Cazden, 1988). The notion of scaffolding proposed by Wood, Bruner and Ross (1976) provides a good reference for coping with this problem. Many researchers have suggested that scaffolding can enhance comprehension, improve independent learning and application, and promote knowledge transfer (Greenfield, 1984; Bruner, 1985; Pea, 2004). In other words, by adaptively fading out the scaffolding, novice learners can gradually become independent learners (Palincsar, 1998; Mayer, 2004; Hmelo-Silver et al., 2007).

With the aid of advances in wireless communication and mobile technologies, mobile-learning (m-learning) has become a new trend in education, especially for those learning activities conducted in the field (Hwang, Kuo, Yin, & Chuang, 2010; Hwang, Shi, & Chu, 2011). Nonetheless, even though the educational application of wireless communication technology seems to be innovative and interesting, several issues have been revealed when devising instruction to assist students to learn in such a complex learning scenario. One major problem is how to take the

students' knowledge levels into account in a novel and information-enriched situation which may impose additional cognitive load on learners' working memory (Sweller, 1999; Sweller, 2005). Scaffolding helps to make the learning more tractable for learners by arranging different target tasks which are achievable, manageable, and within the student's zone of proximal development (Quintana et al., 2004). Scaffolding can also decrease the cognitive load by guiding the novice learner to focus on aspects of the tasks that are directly relevant to the learning goals (Salomon et al., 1991; Hmelo-Silver et al., 2007).

Most of the current mobile learning designs provide online feedback only to multiple-choice items (e.g., Chen, Kao, & Sheu, 2003; Chu et al., 2010; Hwang, Wu, & Ke, 2011). To foster the in-field observation and inquiry competences of students, this study proposes an authentic mobile learning system with in-field scoring rubrics based on a three-layer worksheet design. The working memory load in this learning system was carefully adapted to match most students' challenge levels. Accordingly, online scoring feedback for each task was developed to encourage students to deeply engage in learning. In other words, the automated scoring feedback was designed to help students effectively clarify the content knowledge, focus on the learning targets, and facilitate their inquiry progress. To evaluate the effectiveness of the proposed approach, an experiment was conducted to compare the learning performances of the students who learned with the mobile learning system and those who took the traditional in-field learning approach.

Literature review

Using mobile technology to facilitate indoor and outdoor learning has become a growing trend in education. Various studies have examined the use of such new technologies in school settings in an attempt to provide learners and educators with support that is more active and more adequate (Chen et al., 2003; Cavus & Ibrahim, 2009; Chen et al., 2009; Hwang & Chang, 2011). Previous studies have shown that mobile devices, such as PDAs (Personal Digital Assistants) or smartphones, can be used as a cognitive tool to efficiently provide information and feedback relevant to the current learning situation (Hwang et al., 2009; Hwang, Chu, Lin, & Tsai, 2011; Vogel et al., 2010). Consequently, learners will have more adequate mental capacity available to focus on specific learning tasks, which significantly improves student motivation and learning outcomes (Lai et al., 2007; Tan et al., 2007; Chu, Hwang, & Tsai, 2010). Furthermore, the portability feature that extends the learning environment from traditional classrooms to authentic contexts and appropriate cultures has been considered as being an important benefit of using mobile devices to learn (Juniu, 2002; Hwang, Tsai, & Yang, 2008; Hwang, Chu, Shih, Huang, & Tsai, 2010).

Even though mobile learning has been recognized as being an effective learning approach (Rogers & Price, 2009; Chu, Hwang, Tsai, & Tseng, 2010), there are few sound instructional design models in this area (Chiou, Tseng, Hwang, & Heller, 2010), especially with respect to the model of cognitive learning theory. Through synthesizing several mobile learning projects in the context of fieldtrips and outdoor experiences, e.g., *Ambient Wood* (Rogers et al., 2005), *Environmental Detectives* (Klopfer et al., 2002) and *Savannah* (Facer et al., 2004), Rogers and Price (2009) have suggested that one of the main challenges in mobile learning is to avoid information overload so that students are not too bewildered with an overly complex situation. Therefore, constant guidance provided by teachers, facilitators or learning systems, and explicit structure in the activities are key components for successful mobile learning (Scarlatos, 2006). Researchers have indicated that unguided or minimally guided instructional approaches could lead to less effective and efficient learning than guided instructional approaches owing to the ignorance of the structures that constitute human cognitive architecture (Sweller, van Merriënboer, & Paas, 1998; Kirschner, Sweller, & Clark, 2006). Furthermore, instructional design without solid rationales or theories may not take good advantage of new technologies.

Cognitive Load Theory (CLT) plays a major role in the theory of cognition and instructional design, and could provide an informative reference for developing such a sound learning environment (Sweller, 1999; Sweller, 2005). A key assumption of CLT is that human working memory capacity is limited, and that overloading working memory hinders learning (Sweller et al., 1998; Paas, Renkl, & Sweller, 2003). Accordingly, to facilitate learning, the working memory load needs to be carefully adapted to match the students' challenge level. In terms of CLT, the intrinsic cognitive load is essential for achieving specific learning goals. The more elements and inter-relationships among elements that the to-be-learned material consists of, the higher the intrinsic cognitive load will be. In the outdoor ecology inquiry learning of this study, the students needed to use learning resources from both the real world and the digital world; moreover, there was a need to complete their observations during several field trips. Without a careful

learning design, the intrinsic cognitive load of the participants could be very high. In this study, two strategies were considered to help the students manage the cognitive load without exceeding the limits of their working memory capacity. First, the provision of various process worksheets (or worked examples) rather than a full problem to be solved helped the students break the learning activities into smaller tasks. Secondly, the separation of a three-layer worksheet consisting of different format and cognitive category tasks stimulated them to further foster in-field observation and inquiry competences.

Additionally, situated in an unfamiliar and information-enriched space, the students needed more direct information and feedback on a just-in-time basis to fill the gap between the complexity of the abundant to-be-learned material and their lack of basic knowledge about the ecosystem. To take the extraneous cognitive load into account, the PDAs used in this study played the role of a mobile e-library that provided corresponding supplementary materials during the field trips. This facility prevented the participants from spending too much time searching for information from the paper-based materials during or after the learning activities. As such, unnecessary information searching and processing was reduced, resulting in a lower extraneous cognitive load. In addition, the hints in the form of multiple-choice and short-answer questions provided step-by-step guidance to the students, so that they could focus on the information concerning the learning task they needed to work on at the time.

Mobile learning environment with progressive learning tasks

Three-layer observation learning framework for mobile ecology inquiry

This study proposes a three-layer framework for mobile learning (as shown in Figure 1) to balance students' learning pressure and the challenges they face. The first layer uses multiple choice items and online feedback to clarify the students' basic knowledge. The second layer provides short response items to help students focus on crucial observations. The students are encouraged to take notes and pictures for their inquiries. The third layer suggests that students answer their own questions and provide relational descriptions of the ecosystem to integrate and extend their conceptual knowledge.
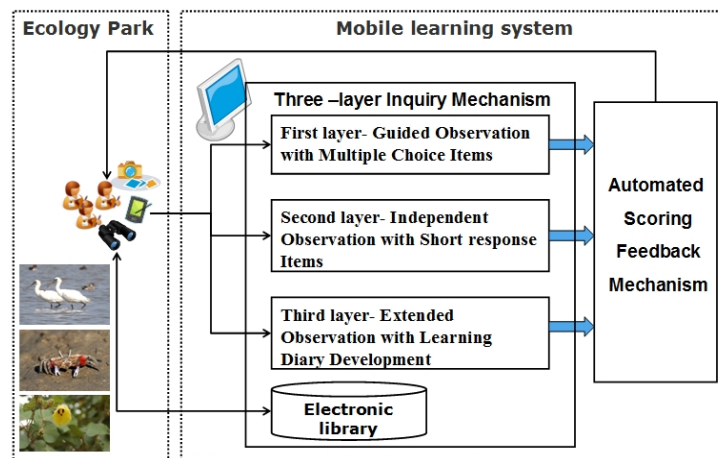
Figure 1. The three-layer observation learning scaffold design

In addition, designed process worksheets provide sections for students to take notes and do diary writing and to raise further questions autonomously for the extended inquiry after the field trip. The scoring feedback is devised to motivate the students to further elaborate their records, reflections and inquiries. Students depend on their learning status to adaptively decide whether to immediately finish their work in the field or to catch up on all their missing data later on the web. Once the students' unfamiliarity with the mobile devices and the outdoor learning activity is actually eliminated, they are able to access more cognitive resources to help them link the incoming information with their prior knowledge base, and to reflect on or monitor their performance. Ultimately, the design of the three-layer scaffolding, from guided observation, independent observation, to personal reflection, sequentially, stresses the need to gradually improve students' competence in terms of contextualization, internalization of ecological knowledge, and reflective thinking.

196

The numbers of the different format and cognitive category tasks embedded in the observation activities are provided in Table 1. There are three different types of tasks (multiple choice, short response, and extended response) and two different cognitive levels (guided and independent observations). The multiple choice items are used to clarify the students' basic knowledge. The adaptive feedback is provided online. Only short responses are required for the field observation tasks. The time-consuming extended response tasks are completed after the students get back to school.

Table 1. The task distribution of the mangrove observation worksheets

Interface	Item type	Guided observation	Independent observation	Contrast and integration
PDA	multiple-choice	25	11	7
	multiple true-false	0	4	3
	short response	3	3	3
PC	extended response	4	4	4

The students can search for specific information from an e-library while they are working on the worksheets via the PDA, as shown in Figure 2. In the first-layer learning tasks, the learning system guides the students to observe the learning targets by asking a series of questions to clarify their factual knowledge. Based on their responses, the system then determines the next learning step, such as suggesting that they "observe the learning target again," "search for more information from the e-library" or "go to the next task."

Figure 2. The e-library interface

For the second-layer learning tasks, the students are encouraged to take notes on the note section of the PDAs about what they have observed autonomously in the field. In addition to the PDAs, each student is equipped with a telescope and a digital camera, with which they can observe the distant targets and take photos of what they have found to be interesting, as shown in Figure 3. After completing the collection of field observation data, the students then upload those records to the learning system through the wireless network.

Figure 3. Photos of learning activities in the field

After the observation activity, the students return to the computer classroom for the third-layer learning tasks. They can browse the data they have uploaded to edit their learning diaries with a personal computer; moreover, they are asked to extend the descriptions they have made in the field based on the notes and photos taken. They can also view

the teacher's ratings and feedback on their worksheets while editing their learning diary. The purpose of editing the learning diaries is to provide opportunities for them to summarize and reflect on the field observations for further inquiries.

In-field scoring rubrics

There were two parts to the automated scoring mechanism: short responses on the PDA, and extended responses on the computer (as shown in Table 2). These scoring rules are developed based upon human rater scoring rubrics (Table 3). Human rater scoring rubrics were available online to communicate the major learning objectives. The first part of the automated scoring rules evaluates the students' observation skills in terms of the quality and quantity of the observation responses on the PDA. For example, if a student provides 10 records on the PDA, he or she gets 4 points for the PDA section worksheet. The second part evaluates the student's extended observation responses on the computer after the field observation activities. If a student provides 2 appropriate relationship descriptions in the diary, he or she gets 3 points. In this study, the students were all familiar with the scoring rubrics, because the instructors explained the scoring rules clearly at the very beginning of the field trips.

Table 2. The scoring rubrics for the observation skills

rating / elements	4	3	2	1	0
Responses in PDA					
quantity	10	6-9	3-5	1-2	no R.
accuracy	7	5-6	3-4	1-2	no R.
question	7	5-6	3-4	1-2	no R.
Responses in diary					
features	5 well described	5 relevant	3-4	1-2	no R.
relationship	3	1-2	1-2	incorrect	no R.
Inquiry	3 success	2	1	0	no R.
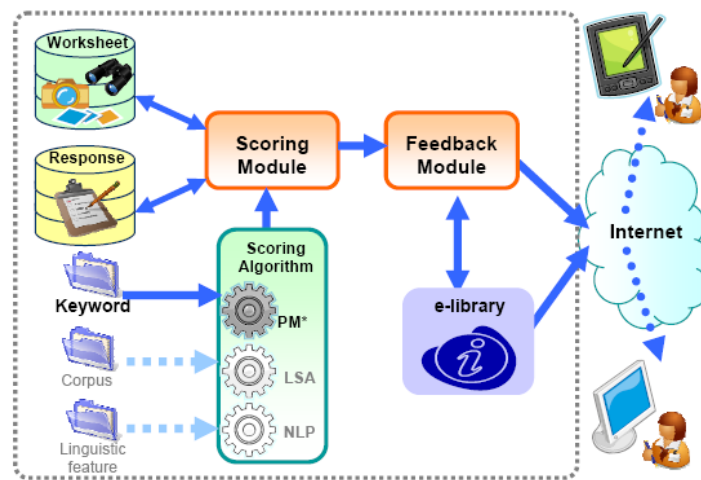
*PM: Pattern Matching, LSA: Latent Semantic Analysis, NLP: Natural Language Processing

Figure 4. The architecture of the automated scoring system

Figure 4 shows the architecture of the automated scoring system for the PDA-integrated learning environment. The feedback provided by the system includes scores, correct answers, explanations and references. The purpose of developing the system is to continuously sustain students' efforts towards achieving the learning goals. A pattern-matching algorithm is employed to compare the similarity between the students' descriptions with the sample description provided by the content expert. In each observation worksheet, three short response tasks are presented. For each task, the content expert was asked to provide some sample responses. For each response, there are three to eight keywords related to the learning task. The keywords and their synonyms for each sample response were then extracted and added to the keyword set of that task by the research team. During the learning activity, each student is

198

allowed to answer a question twice. The keywords in the student's answers are compared with those in the keyword set of the task. A score of zero to four is assigned based on the number of matching keywords. The system also provides three different kinds of qualitative feedback, namely, "Good job! Your descriptions are correct and detailed." for 3-4 points, "Correct descriptions, but more details are needed." for 1-2 points and "Please search for supplementary materials in the e-library and modify your description." for 0 points.

The accuracy of the automated scoring mechanism was evaluated by comparing its scores with those given by two human raters. Table 3 shows an example of contrasting the human scoring rubrics and automated scoring rules for a constructed response task. Raters apply scoring rubrics to rate students' responses, while the scoring system employs the pattern-matching method based on a pre-defined keyword set. In this example, the learning task is "Describe the physical features and eating behaviors of male fiddler crabs" and the keyword set is "white body, a large front claw, a small claw, mud, and organic." In this study, the inter-rater reliability between the two raters for the three tasks and the total scores are .94, .91, .90, and .93, respectively. For the scoring consistency between the human raters and the computer system, the correlation coefficients for the tasks range from .82 to .93, revealing that the automated scoring has reached an acceptable consistency with the human rating.

It should be noted that the objective of providing feedback in such in-field inquiry-based activities is quite different from that in web-based learning activities. In a mobile or ubiquitous learning activity, the main learning content consists of those real-world learning targets in the field. It is improper to provide complex feedback or learning content with rich information to interfere with students' in-field observations, in particular, on the mobile devices with small screen size. Therefore, in this study, only necessary feedback, such as the scores and short responses that reflect individuals' present performance, is provided.

Table 3. A contrasting example of human scoring rubrics and automated scoring rules

	3 points	2 points	1 point	0 point
Human rating	Sufficient descriptions of physical features and eating behaviors.	Descriptions of two required features but only one of them is sufficient.	Description of one feature only or descriptions of two features partially.	Descriptions are irrelevant to the task.
Automated scoring	4-5 keywords	2-3 keywords	1 keyword	0 keywords

Experiment design

To evaluate the applicability of our approach, an experiment was conducted in the Chiku mangrove wetland located in the southwest coastal region of Taiwan for a science curriculum activity. The wetland is the largest and the most intact lagoon in Taiwan. The main water source of the wetland is Zengwun River which brings large varieties of biological, nutritive products, thus forming an excellent habitat for wildlife. Many shorebirds, wildfowl and egrets gather at sandbars in the river, including the famous endangered "Black-faced Spoonbill." The aim of this learning activity was to foster the students' observation, description, and inquiry competences, which are considered as important educational objectives of natural science courses in Taiwan; therefore, the learning activity was designed as part of the distinguishing curriculum of selected elementary schools.

Participants and learning procedure

The subjects were forty-nine 5th and 6th graders aged from 11-12 years old. Twenty-four students were assigned to the control group and twenty-five students were the experimental group. The experimental group experienced the field trips within four months in the Chiku mangrove wetland and learned with the mobile learning system proposed in this study. On the other hand, the control group learned with traditional inquiry-based approach; that is, they were guided by paper worksheets to obtain information about the ecological system from the teacher's presentations, the web and the in-field observations.

To ensure that the students were able to focus on the major learning objectives while making explorations in the field, an orientation was given to introduce the learning tasks. The orientation included a whole picture of the

199

learning environment and the learning tasks. The students in the experimental group further received a 40-minute lesson on some basic practices regarding the use of the PDAs.

For the first trip, the students in the experimental group spent about three hours completing the observation tasks with the worksheet. For the second trip, the students spent two hours visiting an ecology pond near Chiku. They were encouraged to observe and raise questions for further studies. The third trip was a particularly interesting outing for the students. They took a boat to observe the ecology system of a green tunnel for 30 to 40 minutes. They then spent another 2 hours clarifying their own puzzles arising from their previous observations or extending their own inquiries in this trip. They also used digital cameras to collect data, and telescopes for long-distance observations during the learning activities. After each field trip, the students were asked to go back to the computer classroom to complete a learning diary by searching for relevant information from the Internet, making reflections upon their experiences in the field and reorganizing what they had recorded in the field.

Two experienced teachers were then asked to rate the worksheets and learning diaries submitted by the students. Finally, the students took a questionnaire concerning their attitudes toward the mobile learning activity for field observations. In addition, a reward system was used to balance the students' learning motivation and fun experiences during the fieldtrip. The students were told that they would receive a certificate if they completed the learning tasks; moreover, the five students with the highest scores would receive a gift.

Instrument

The science inquiry ability assessment developed by Lin (2009) was applied to assess students' inquiry abilities. The assessment consisted of three facets, i.e., retrieving information, interpreting information, and reflecting on and evaluating content of on-line texts. There were a total of 12 items in the assessment. Its alpha coefficient was .90. The correlation between the assessment and the school science grade was around .40, showing acceptable reliability of the assessment.

Data collection design

To evaluate the improvements in the students' learning performance, the automated scoring results of the students in the first field trip and the third field trip are compared. The scoring aspects included were the students' observation records, questions raised, descriptions of the learning targets, and the surrounding environment. Those records were also rated by two teachers to check the validity of the automated scoring results. The consistency coefficients of the human and machine ratings range from 0.82 to 0.93. In addition, a questionnaire was used to collect the experimental group students' feedback on using the PDAs while participating in the field trips, including their attitude toward using the PDAs to learn in the field, their feelings about the pressure of using the PDAs to learn in the field, the usefulness of the e-library, and the helpfulness of the PDA learning system. The questionnaire consists of four items with a four-point Likert scale and one open-ended question.

Results and findings

Science inquiry ability assessment of the two groups

The science inquiry ability assessment was used as the criterion variable. One-way analysis of covariance was applied to examine the effects of different learning conditions. The results indicated that the experimental group's post-test score of the science inquiry ability assessment was significantly better than that of the control group (8% variances accounted by group variable, as shown in Table 4). That is, the proposed mobile learning system could substantially promote the students' learning performance in in-field inquiry-based learning activities in comparisons with the traditional approach.

The lower growth of the control group on the inquiry abilities (from 0.49 to 0.58 in mean) could be attributed to a lack of scaffolding for reducing their extraneous cognitive load and increasing their germane cognitive load that can stimulate learners to engage in more meaningful inquiry learning (Sweller, 1999; Sweller, van Merriënboer, & Paas,

200

1998). The finding revealed several possible problems in traditional inquiry-based approach, including the insufficiency of in-field experiences during the learning process and the lack of instant guidance and feedback for cultivating students' higher order thinking abilities in fields (Hwang, Wu, Tseng, & Huang, 2011).

Table 4. Analysis of ANCOVA of the on-line science inquiry abilities for two groups

Group	N	Pre-test		Post-test		F	η^2
		Mean	SD	Mean	SD		
Experimental	25	0.35	0.69	0.94 (0.97[#])	0.81	4.72*	0.08
Control	24	0.49	0.68	0.58 (0.55[#])	0.66		

Note. # adjusted mean   * $p < .05$

Table 5 further shows the t-test results of the in-field performance of the experimental group students on the first and the third trips. The results suggest that they made substantial progress in every aspect, including their observation records, the questions raised, and their descriptions of the learning targets and the ecology environment. By analyzing the embedded worksheet data, we can conclude that the scaffold design successfully helped them to enhance their ecology inquiry skills. This internal checking design is direct, valid, efficient, and economical in terms of achieving the learning objectives. Whenever students submit their responses, the scoring data will be ready for analysis. Using automated scoring data, the students' learning progress can be evaluated by objective statistics without any extra costs.

Table 5. The t-test results of the extended responses between trips 1 and 3

		Mean	SD	*t*-value
Observation records made on the trip	Trip 1	2.72	1.02	6.56**
	Trip 3	4.08	1.26	
Questions raised on the trip	Trip 1	0.76	0.60	8.28**
	Trip 3	2.28	0.84	
Descriptions of learning targets in the learning diary	Trip 1	4.48	1.09	3.67**
	Trip 3	5.32	1.44	
Descriptions of ecology relationships in the learning diary	Trip 1	2.36	0.70	2.22*
	Trip 3	2.72	0.46	
Questions raised in the learning diary	Trip 1	1.04	0.84	13.50**
	Trip 3	3.20	0.82	

Note. * $p < .05$, ** $p < .01$, N = 25

Outcomes of the students with different performance levels

According to the learning portfolios of the experimental group students, the teachers categorized them into three performance levels after a 30 minute discussion. The performance levels were mainly determined by the accuracy of the students' descriptions and the number of questions they raised. The advanced students used more scientific vocabulary to describe what they had observed, and provided more accurate and detailed descriptions; in addition, most of the questions they raised were scientifically oriented. On the contrary, the descriptions submitted by the basic level students contained more inaccurate content with less scientific vocabulary; moreover, the questions raised were shallow. As shown in Table 6, about half of the students were classified as being at the proficient level, implying that those students were good at describing the main features of their observations, although some of their descriptions could be insufficient or inaccurate. Moreover, nearly 28% of the students reached the advanced level; that is, they were able to use scientific vocabulary to accurately describe what they had observed in detail.

Table 6. The means of the short responses for different level students

Level	Quantity	Accuracy	Question
Advanced (28%)	3.14	2.86	3.00
Proficient (44%)	2.55	1.36	2.00
Basic (28%)	1.43	0.57	0.57

Note. N = 25

Table 7 shows the extended responses of the different performance level students in their learning diaries. It was found that the pattern of their performance was similar to that shown in Table 6. However, for those basic level students, the scores in Table 6 are noticeably lower than those in Table 7; that is, providing responses immediately in the field is a challenging task for those basic level students since they need to face a complex learning scenario that consists of real-world learning targets as well as the learning task instructions or supplementary materials from the learning system at the same time. For the learning reflection part, the differences between levels are also smaller, except in the extended inquiry learning. The basic level students made few autonomous inquiries (0.86) since they raised few questions. More stimulating examples may be needed to help them to raise some scientific-oriented questions. On the other hand, the advanced students outperformed the others in every aspect; that is, they were quick to capture the critical features of the observed targets, and their descriptions were detailed, accurate, and related to their own experiences.

There were significant differences among the different level students. The characteristics of the different levels in terms of their observation, description and reflection skills are summarized as follows. For the basic level students, the number of valid short or extended responses was limited (around 2); the observation records were few and incomplete; their observation descriptions did not focus on the learning targets; and the extended responses in their learning diaries were shallow. For the proficient level students, the number of valid short responses was around 5, while the number of valid extended responses was around 3; most of their descriptions were relevant and scientific oriented; and about 1 autonomous question was successfully pursued. For the advanced level students, the quality and quantity of the observation descriptions were both good; the number of short responses and extended responses were around 7 and 4 respectively; most of their descriptions were relevant and accurate; and about 2 autonomous questions were pursued successfully.

The basic level students might have put too much effort into observing species or using the technology devices to search for information such that they could not cope with the mobile ecology inquiry context. Therefore, the number of questions they raised was significantly lower than the number raised by the advanced level students. In other words, the students' cognitive load played a key role in their learning progress. Even though the online worksheet and scoring feedback could partially satisfy the basic level students' need for support for knowledge and concept learning, their questioning competence was still too weak to allow them to pursue their own inquiries.

Table 7. The means of the extended responses for different level students

Level	Observation		Reflection	
	Feature	Relationship	Reflection	Inquiry
Advanced (28%)	2.71	2.14	2.00	2.00
Proficient (44%)	1.82	2.09	1.36	1.73
Basic (28%)	1.71	1.71	1.29	0.86

Note. N = 25

Question 1: Describe the physical features, living environments and special records of "Kandelia obovata" in the field. Your descriptions will be scored based on the aspects of quantity, quality, accuracy and relevance.	
Category	Descriptions
Physical features	*Rhizophoraceae family, a small evergreen tree, five meters in height.* *It has grayish-brown bark. Its leaf has opposite leaf arrangement and is long oval. The leaf has thick skin to prevent loss of water.* *It's a viviparous plant. Its pen-like viviparous seedling stretches out from circular cone-shaped mature fruit. The green viviparous seedling turns reddish-brown and falls into the muddy ground when mature.*
Living environments	*The living area is between river and sea in tropics or subtropics.*
Special records	*The color of bark is grayish-brown. The base of the tree significantly thickens into a plank shape. The dense prop roots branch out into soft mud from the tabular root.*

Figure 5. An example of an advanced level student's performance

A sample of an extended response of an advanced level student is given in Figure 5. This record includes 3 features pertaining to the leaf, 2 features of the fruit, 3 features of the body or branch of the tree, and one feature related to the growing environment. The automated scoring result can easily assess that the student performed well. He or she was able to describe the features of the observed plants as well as their surrounding environment. With appropriate guidance in the field, nearly a quarter of the participants were able to provide such detailed descriptions of their field observations in this study. Most of this level's students are ready to pursue their own inquiries autonomously.

Students' perceptions of the mobile ecology observation learning system

At the end of the third trip, a questionnaire was used to collect feedback from the students in the experimental group about their attitudes toward and perceptions of the mobile observation activity. Twenty-two students completed the questionnaire. It was found that 82% of the participants showed positive attitudes toward using the PDAs in the observation activities; for example, several students expressed that "I am more willing to participate in outdoor learning activities than before."

Moreover, 91% of the students felt that using mobile devices to learn in the field could reduce their learning pressure in comparison with the traditional approach. For example, one student indicated that "I feel that it is easier and less pressured when using the PDA system to learn in the field in comparison with the traditional approach." Other students also expressed similar feelings. Around 95% of the students indicated that using the PDA system to learn had made them concentrate more on the learning targets than they would in the traditional approach.

On the other hand, only 50% of the participants agreed that the e-library was helpful to them during the learning activity. This information suggests that more efforts need to be made in training the students to search for and use relevant information in the e-library. For example, it could be helpful to extend the 30-minute e-library introduction and searching practice in future applications.

Conclusions

In this paper, a three-layer mobile learning worksheet design with in-field scoring rubrics was developed to assist students in identifying their learning targets, focusing on critical details of observation, and extending their own inquiry learning. The results suggest that proposed mobile learning approach could substantially promote the students' in-field inquiry performance in comparisons with the traditional approach. The students' perceptions of the learning system further suggested that the learning and assessment design proposed in this study was workable and enjoyable for most of the participants. Moreover, the collaborating teachers thought that the proposed mobile learning approach successfully engaged the students in the outdoor ecology inquiry activities in a spiral manner; that is, the three-layer worksheets and the corresponding scoring feedback helped the participants at different performance levels focus on their observation tasks and raise their own questions for ecosystem knowledge construction. Such a learning design provides an opportunity for elementary school students to conduct scientific observations in a well-supported mobile learning environment.

Although the experiment results and feedback from the students have demonstrated that our approach is applicable and effective for integrating mobile learning systems into outdoor learning designs, it should be noted, however, that about 28% of the students did not exhibit good performance. Their observation descriptions were rather shallow and even irrelevant to the learning tasks, which could be due to their lack of prior knowledge, barriers in understanding the objective of the learning tasks, or their lack of observation or communication ability. To provide more effective assistance to such students, it is important and challenging to investigate in depth the factors that might affect the learning performance of such students, and develop adaptive mobile learning mechanisms by taking those factors into consideration. If sufficient time is allowed, most students can make reasonable progress in worksheet tasks. In other words, the time constraint in the field may negatively affect basic level students' performance. Thus the time distribution issue should be considered in future practice (Hwang, Kuo, Yin, & Chuang, 2010). Furthermore, it would be of great value to integrate the mobile learning system into the regular science curriculum (Hwang & Tsai, 2011; So, Kim, & Looi, 2008; Wong, Chin, Tan, & Liu, 2010). In addition, the continuous assessment data from the automated scoring system could also be valuable for describing the change in the students' attitudes and conceptual structure. An online scoring mechanism for constructed response tasks is a promising direction for future mobile

inquiry research; in the meantime, more rigorous experimental data are needed in the future for clarifying the feedback effect in this mobile learning and assessment design model.

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204

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