

## Educational Affordances of a Ubiquitous Learning Environment in a Natural Science Course

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### ABSTRACT

Educational affordances are worthy of being explored because the affordances of Information and Communication Technologies (ICT) provide the pedagogical effects for promoting cognitive acceleration, increasing the self-management of students, facilitating data collection, and presentation in science learning. This study aims to explore educational affordances on a course with a learning environment. To address this research goal, this study employed a ubiquitous learning environment termed the Environment of Ubiquitous Learning with Educational Resources (EULER) and conducted a natural science course for eight weeks. The participants included elementary school teachers and students. Detailed studies of how the students use EULER and how this course affects their learning have enabled us to identify specific educational affordances and their potential application in supporting learning. This study describes thirteen educational affordances that were revealed through the responses given by students in an open-question survey and interviews as well as through transcripts from researcher observations and student discussions. These educational affordances of ubiquitous learning environment employed in the natural science course have implications for current and future developments in pedagogy.

### Keywords

Collaborative learning, Educational affordances, Game-based learning, Natural science learning, Ubiquitous learning

### Introduction

The term “affordance” was coined by the perceptual psychologist J. J. Gibson, who developed an “ecological” alternative to cognitive approaches (Gibson, 1977). Gibson (1977) defined affordances as what the environment offers to humans and what it provides or furnishes, which may be for good or ill; it emphasizes possible actions that the observer perceives as feasible in the environment. Norman (1988) defined affordances as opportunities for action, that is, the perceived and actual fundamental properties of a thing that determine its possible uses. Independent of perception, affordances exist whether or not the actor cares about them, perceives them, or has perceptual information about them (Gaver, 1996). These definitions suggest that the same environment perceived by different observers may produce different perceptions of affordances, which are determined by the culture, social setting, experience, and intentions of the observer (McGrenere & Ho, 2000). On the basis of the abovementioned definitions, affordances cut across the subjective/objective barrier. Affordances are objective in that their existence does not depend on value, meaning, or interpretation. Additionally, affordances are subjective in that an actor is needed as a frame of reference; the actor and the environment make an inseparable pair (McGrenere & Ho, 2000).

Kirschner (2002) further defined educational affordances as those characteristics of an artifact that determine if and how a particular learning behavior can possibly be enacted within a given context. Webb (2005) illustrated that the affordances of information and communication technologies (ICT) provide the following pedagogical effects in science learning, which are promoting cognitive acceleration, enabling a wider range of experience in science learning, increasing self-management of students, and facilitating data collection and presentation. Therefore, the educational affordances are worthy of being explored and discussed.

### Related works and our work

Mobile learning that employs mobile devices as learning tools has been thriving since recent years. Many studies are exploring the educational affordances that mobile devices can offer. For example, Klopfer, Squire, and Jenkins (2002)

proposed five educational affordances of PDAs: portability, social interactivity, context sensitivity, connectivity, and individuality. Patten, Sa´nches, and Tangney (2006) explored current mobile applications and used the functionality to describe what might be understood as the following seven educational affordances: administration, referential, interactive, micro world, data collection, location awareness, and collaboration. Churchill and Churchill (2008) did an empirical study and found PDAs providing five educational affordances: a multimedia-access tool, connectivity tool, capture tool, representational tool, and analytical tool. Churchill and Churchill (2008) claimed that understanding of educational affordances is important in the context of planning a suitable intervention to support pedagogically effective integration of PDA technology.

In this study, we define the learning package (LP) as the combination of computer-assisted learning environment and course that includes diverse learning tools, rich learning resources, theme-based learning activities, and real-life learning contexts. We argue that the educational affordances of an LP are obtained from four elements: (1) Learning tools: Diverse learning tools used in the computer-assisted learning environment can provide support for learning, thus helping learners to acquire knowledge. (2) Learning resources: Rich learning resources provided in courses can offer support for basic knowledge to learners, allowing them to integrate existing knowledge and access information to build new knowledge. (3) Theme-based activities: Interesting theme-based learning activities provide the basic learning scaffolds to learners by prompting issues to be studied, guiding them to finish tasks, providing ideas and the framework for conclusion, and developing their skills to solve problems. (4) Learning contexts: Real-life learning contexts can increase the usefulness of knowledge, induce learners' motivation to learn, and reinforce learning experiences.

Our primary research question is as follows: What are the educational affordances of an LP? Although learners' perceptions should be the best sources of educational affordances, this study uses a learning environment that includes diverse learning tools and rich learning resources as well as to conduct a natural science course that includes various theme-based learning activities in a real situation for exploring the educational affordances. This study also investigates the perceived degree of educational affordances that the students identified.

## Methodology

A case study was conducted in a classroom and at Guandu Nature Park, a famous wetland in the Taipei area (Wild Bird Society of Taipei, 2009), for an eight-week natural science course. Qualitative and quantitative analyses were used to explore the educational affordances and perceived degree of educational affordances.

### Course

The advantages of problem-based learning (PBL) include improvements in self-directed learning, self-motivation, problem-solving skills, and knowledge-application skills (Stepien and Gallagher, 1993). Game-based learning (GBL) has the potential to make learning more learner centered, easier, enjoyable, interesting, efficient, and effective than non-game-based learning does (Prensky, 2001; Virvou, Katsionis, & Manos, 2005). GBL can improve students' learning achievement, learning motivation, attention, and creativity (Eow *et al.*, 2009). Moreover, collaborative learning (CL) can increase learning motivation (Ushioda, 1996), improve achievements (Duin, 1984), and achieve group goals (Nichols, & Miller, 1994). Therefore, in order to discover educational affordances, this study develops a natural science course based on the PBL, CL, and GBL strategies that included several theme-based learning activities.

The course was entitled "How can the gradually disappearing wetland ecosystems in Taiwan be protected and restored?" The learning objectives of this course were as follows: (1) understanding wetland habitats and wildlife, (2) understanding the wetland ecological systems, (3) understanding the relationship between wildlife and environment, and (4) finding the methods of environmental protection. The course includes nine topics: (1) Functions and value of wetland, (2) Migrant, (3) Plant, (4) Crab, (5) Insect, (6) Mammalia, (7) Amphibia, (8) Fish, and (9) Invertebrate. The course includes the following five activities:

Activity 1. Understanding the ecology of wetlands (weeks 1–4)

Students perused the course material, browsed media resources, collected information, and shared knowledge to understand wetland ecosystems by using PDAs in the classroom.

#### Activity 2. Treasure hunt game (week 5)

Each student used PDAs with radio frequency identification (RFID) readers when visiting five scenic areas (riverside biological area, pond biological area, coastal forest area, crab watching area, and bird watching area) following the instructions on a treasure map.

#### Activity 3. Wetland rescue (week 6)

Each team selected a collaborative team project from among the predefined themes: “What is the interdependent relationship among biological species in a wetland?” “Why do wetlands gradually disappear?” “How to protect wetlands?” and “How to restore wetlands?” The team members were required to develop hypotheses, find evidence, synthesize knowledge, and explain phenomena outside the classroom.

#### Activity 4. Unexpected encounter (week 7)

Each student adopted mobile augmented reality (m-AR) to observe virtual creatures rarely seen in the wetland areas during the season.

#### Activity 5. Survey and interviews (week 8)

The teachers conducted an open-question survey with the students, and the researchers conducted in-depth interviews with the students.

### Learning environment

The rapid development of modern computer science and sensor technology has enabled many new ubiquitous computing applications. Ubiquitous learning has the following primary characteristics: permanency, accessibility, immediacy, interactivity, situation, calmness, adaptability, seamlessness, and immersion (Liu, 2009). Many investigations employed the ubiquitous learning concept to enhance natural science learning (Tan, Liu, & Chang, 2007), share knowledge, provide help (El-Bishouty, Ogata, & Yano, 2007), and cultivate student problem-solving ability (Liu, Tan, & Chu, 2009).

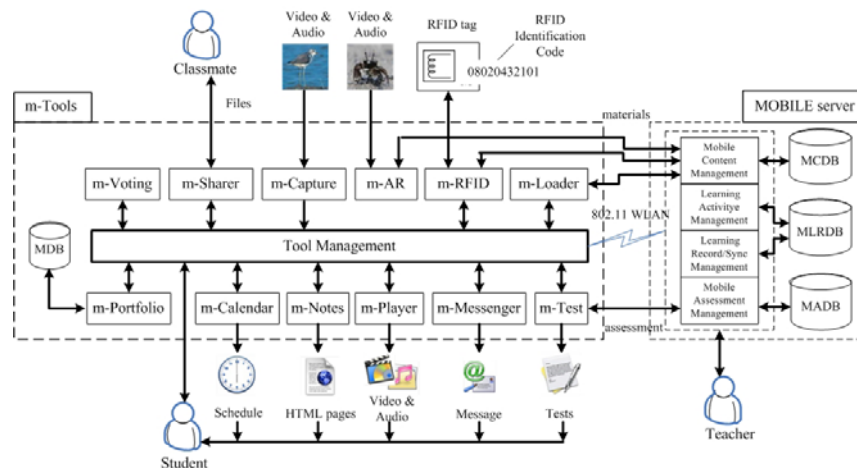


Figure 1. The system architecture of EULER

This study employed a ubiquitous learning environment, EULER, to help natural science learning. EULER consists of two subsystems, Mobile Interactive Learning Environment (MOBILE) server, which is built on a laptop computer for teachers, and mobile-tools (m-Tools), which are built on PDA platform for students. Teachers input material into the Mobile Content Database (MCDB) via Mobile Content Management (MCM) and establish assessments in the Mobile Assessment Database (MADB) via Mobile Assessment Management (MAM). The personal portfolio tool, m-Portfolio, saves each student’s personal learning portfolio into the Mobile Learning Record Database (MLRDB) of the mobile server, making it available for teachers to review and assign grades. The MLRDB stores the student’s

records, including assignment grades, reading times, number of discussions, and instances of information sharing. Teachers preinstall the tests into the mobile server and conduct these tests using a MAM unit. Teachers use a Learning Activity Management (LAM) unit to construct a virtual classroom for each course, which supports many learning functions including bulletin boards, forums, voting, chatting, assignments, tests, and instruction. The m-Tools has fourteen functions, such as m-Messenger (receiving teacher guidance), m-RFID (processing RFID internal code), m-Loader (accessing course materials), m-Browser (browsing the contents), m-Player (playing multimedia files), m-AR (displaying virtual objects), m-Capture (recording videos and static photos), m-Notes (compiling information into articles), m-Sharer (sending data to peers), m-Test (taking tests), m-Calendar (organizing personal schedules), m-Voting (presenting personal idea), and m-Portfolio (recording personal learning records). The personal learning portfolio was saved in the m-DB. Figure 1 illustrates the system architecture of the proposed EULER (Liu, Tan, & Chu, 2009).

## Participants

Participants included four natural science teachers and 36 fifth-grade students. All participant teachers had at least ten years of experience in computer-assisted instruction. Students begin to learn natural science from the first grade and Computer Science from the third grade. Therefore, students acquire basic skills in using information technologies to assist learning.

## Procedures

Teachers demonstrated how to use the EULER functions and introduced the course activities to the students before the activities began. Figure 2 is a diagram briefly outlining the experimental procedures and data analysis.

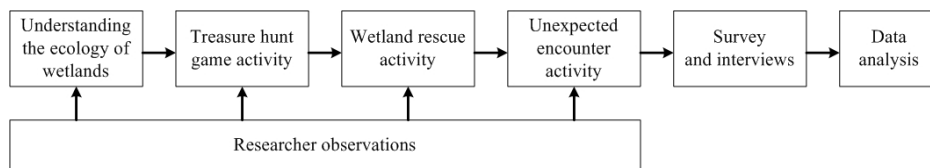


Figure 2. Diagram outlining the procedures of the case study

Activity 1, the “Understanding the ecology of wetlands,” was undertaken in the classroom. By using their PDAs, the students perused course materials and browsed media resources from EULER, collected information from the Internet, and shared knowledge with their classmates in order to understand the creatures and environment of the wetlands.

In activity 2, “Treasure hunt game” activity, the teachers prepared numerous information boards, each with an RFID tag attached. The teachers established the relationship between learning materials and the identification codes of RFID tags and then placed the information boards near the corresponding wetland creatures. Each student carried a mobile device equipped with a video camera and an RFID reader when visiting scenic areas using the treasure map. Each student approaching a scenic area could use the learning device to identify the RFID tag. The detected identification code of the RFID tag was then transmitted via WLAN to the MOBILE server. The MOBILE server recognized the location of the student and then transmitted the context-aware content to the learning device. After completing a learning unit at one scenic area, the student answered four questions and was given a virtual gold coin; he/she then continued to the next scenic area until all five areas had been visited. The student thus accessed context-aware content related to actual wildlife, which enabled game-based ubiquitous learning. Figure 3 illustrates the scenario of treasure hunt game (Liu, Tan, & Chu, 2009).

In activity 3, “Wetland rescue” activity, the students selected a team project from among the themes. In case the students were unable to propose any feasible method even after group discussions, they used the messenger tool (m-Messenger) to request the teacher’s assistance. Under the guidance of the teacher, team members applied m-Capture to capture images or videos as evidential materials. Each team member organized and collected evidential materials and retrieved relevant information from the MOBILE server and then compiled these materials into an article. The members engaged themselves in a group discussion on the basis of the articles and drew an inference for a selected

problem. All articles were then sent to team leaders to edit a rich team report that was submitted to teachers by using sharing tool (m-Share).

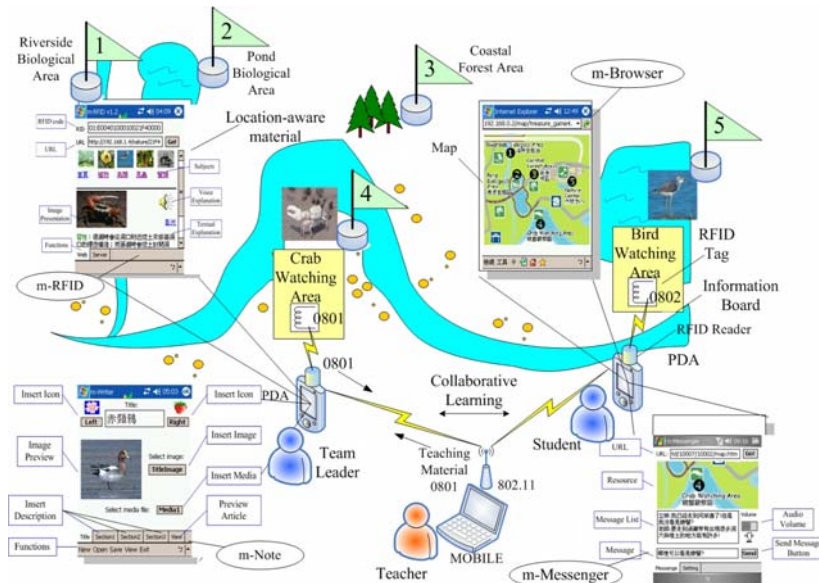


Figure 3. The scenario of treasure hunt game

In activity 4, “Unexpected encounter” activity, each student utilized the AR tool (m-AR) to watch virtual wildlife that would rarely appear in the wetland area during the season. When students approaching a scenic area, the MOBILE server recognized the location of the student and season and then transmitted a virtual 3D animation of wildlife to the students’ learning device. Therefore, the students could understand wildlife that usually appeared in this area. For instance, students could see virtual mandarin ducks swim on a stream shown on the PDA screen through superposed virtual imageries on the live video.

In activity 5, on completion of the course, teachers and researchers conducted an open-question survey, a yes/no-question survey, and in-depth interviews.

### Data sources

Data sources for this case included the students’ written responses to the survey questions, transcripts of in-depth interviews, on-line student discussions, and the researchers’ written observation notes. After the learning activities, a survey was conducted to explore the educational affordances of EULER. The survey included the following open-ended questions. (Q1) How did you utilize m-Tools to assist you in the “Understanding the ecology of wetlands” activity? (Q2) How did you utilize m-Tools to assist you in the “Treasure hunt game”? (Q3) How did you utilize m-Tools to complete the “Wetland rescue” activity? (Q4) How did you utilize m-Tools to complete the “Unexpected encounter” activity? Each student was required to respond to the aforementioned open-ended questions. The transcripts were checked by the students.

In-depth interviews were conducted to explore the students’ points of view, feelings, and perspectives after they completed all the learning activities. The researcher interviewed the students for 20 minutes to understand their opinions about the learning activities. The interviews comprised the following questions: (I1) Which activity do you think is the most interesting? Why? (I2) Which tool do you think is the most useful for aiding in learning? Why? (I3) From which activity do you think you gained the most? Why? (I4) What is your biggest gain from this course? Why? (I5) What new uses for m-Tools in the learning activities did you discover? The in-depth interviews were recorded on an audio recorder.

The data collected from on-line discussions were related to the students’ reflections on their uses and exploration of m-Tools. The researchers observed the students’ learning behavior and their use of m-Tools during the learning

activities, and they documented the learning processes and important findings in the form of notes over a period of eight weeks. The data was organized, and it classified the educational affordances relating to the proposed ubiquitous learning environment and course. Finally, we obtained 36 open-ended questionnaires, 28 interview records, records on 36 topics of discussion, 15 observation records, 6 team reports, and 36 yes/no questionnaires (response rate is 100%). Teachers and tutors helped students to understand the meaning of each question. The 36 response questionnaires comprised 218 responses and were collected from the students.

## Data analyses

The data were collected, organized, and reviewed by researchers who manually use the text mining technique (Feldman & Hirsh, 1997) on features extraction and based on the following steps to obtain the educational affordances:

- Step1. Each student's response was assigned a code; for example, r-q3-s7 indicates the response to question#3 by student number 7.
- Step2. Extract keywords about educational affordances manually from each student's responses, such as the keyword "data collection."
- Step3. Arrange the distinct keywords that were regarded as educational affordances, from all extracted keywords.

In order to obtain the perceived degree of each educational affordance, in quantitative data analyses, we designed the yes/no questionnaire that asked students whether they used the tools/features/methods described in the questionnaire to help in learning activities. The perceived degree of educational affordance is defined as the number of students who reply "yes" divided by the number of students on an educational affordance.

## Results and discussions

Analysis of data sources revealed eight actual educational affordances and five perceived educational affordances. We employed a representative student's response that was paraphrased to enhance readability as a sample for each affordance, and the other students' responses, interview records, and observation records were described in discussion paragraphs.

### Actual educational affordances

***Unconstrained Knowledge Accession***—knowledge construction is the ability to recall specific and isolatable information from learned material (Bloom, 1956). M-Tools can enable students to retrieve learning materials from the content server at any time and place, students through reading, comprehending, and memorizing those materials to construct their knowledge. A student wrote the following in his survey response:

Student 6: I saw many crabs move sideways. I wanted to know whether all crabs move sideways. I employed the browsing tool (m-Browser) to find the answer from MOBILE server, and I found that one of the species, the soldier crab (*Mictyris brevidactylus*), is an exception. Using these ubiquitous learning tools, I could easily acquire new knowledge.

In the researchers' observation, the students were able to use the browser (m-Browser) and player (m-Player) to read materials and play videos. These materials helped them further understand the features, living habits, and feeding habits of animals.

***Real-time Evaluation***—evaluation is a treatment to assess the learning outcomes for achieving specific educational purposes (Anderson & Krathwohl, 2001). The test tool (m-Test) could enable students to take real-time tests and to improve their cognition. A student noted the following in his survey response:

Student 21: Answering questions immediately on the PDA is a new experience. On an electronic test tool (m-Test), colorful graphics and sounds can be attached to each question. Compared with paper-and-pencil

tests, electronic tests are more lively and interesting.

During the interviews, the students stated that they thought using the m-Test to take tests was interesting, and the immediate retrieval of answers was helpful for learning. Therefore, real-time tests improve student outcomes and stimulate interest in learning (Liu, Tan, & Chu, 2009).

**Individuality**—individuality indicates separateness; individuality is the state or quality of being an individual, a student separate from other students and possessing his or her own educational needs, goals, and desires. Klopfer, Squire, and Jenkins (2002) argued that handheld computers provide a unique scaffolding function that is customized to individual paths of investigation. A student noted the following in his survey response:

Student 31: During the learning activities, the portfolio tool (m-Portfolio) automatically recorded the materials I read, stored the graphics of crabs I captured, saved my homework, recorded the treasure hunt games I attended, and kept track of my test performance.

In the interview, a student stated that she recorded the deadline for each assignment on the calendar (m-Calendar). The calendar would automatically alert her one day before each deadline. Therefore, handhelds enable students to configure their own personal settings, profiles, activities, and private portfolios. The learning habits of students who habitually set goals, priorities, and well-organized learning schedules are positively related to average academic performance. Each student read different materials, watched dissimilar wildlife, stirred diverse reception, and procured a diverse learning experience that could be saved in portfolios.

**Diverse Interaction**—there are four interactions in ubiquitous learning: learner-content interaction, learner-instructor interaction, learner-learner interaction, and learner-environment interaction. Interaction in teaching and learning has a positive meaning for learning efficiency and developing thinking ability (Vygotsky, 1978). A student wrote the following in his survey response:

Student 16: Whenever we encountered problems during the “Wetland Rescue” activity, we used the communication tool (m-Messenger) to chat with our teacher and ask for assistance. The teacher also used it to guide us and give hints to the solution. All problems were finally solved after group discussion.

On the discussion forum, a student stated that he posted the following question: “Why do crabs walk sideways?” This issue drew much attention and discussion. Many classmates provided their opinions. Some were interesting and creative. The students browsed classmates’ articles on the forum and shared their opinions. By exchanging opinions, they made many new friends. Therefore, through social interaction processes (e.g., exchange ideas and discuss issues), students improve their comprehension.

**Arbitrary Data Collection**—data could be collected from the students’ observation, recording, investigation, and measurement, or from existing videos, audios, images, and articles that were stored in the content management server. The learning environment enables students to collect data freely and helps cultivate their abilities. A student wrote the following in his survey response:

Student 15: Whenever I observed anything interesting, I would easily use the video-capturing tool (m-Capture) to record the scenes in the PDA. For instance, I saw two crabs that seemed to be fighting, so I recorded them in a video file and uploaded the file to the MOBILE server, which made the video available for others to view.

In the discussion forum, a student said, “In the ‘Wetland rescue’ activity, I easily used m-Capture to take snapshots of the special things I observed, such as a crab digging up its cave, a crab swallowing sand, and a dragonfly perching on a leaf.” Therefore, as learning occurs in a rich natural environment, filled with real creatures, the concepts presented can be meaningfully contextualized.

**Ubiquitous Game Play**—ubiquitous games are developed using ubiquitous technology and game science; in the real environment, players can use devices or equipment at any time and location to play interactive games involving a portion of physical objects and a portion of virtual ones, which allow them to feel personally and physically involved in the games (Liu & Chu, 2010). Games could enable students to increase their learning interest by motivating students at any time and place (Prensky, 2001). A student noted the following in his survey response:

Student 18: In the “Treasure Hunt” activity, when we arrived at the crab watching area, we used the m-RFID tool to get crab-related course materials. We would receive a virtual treasure after we completed the learning and passed a test in each zone. Finally, our team received an award after collecting the five treasures in the shortest time.

In the researcher observation, the students really enjoyed the treasure hunt game, so each team tried to do its best to win the award. One student said, “Although we got virtual treasures in the treasure hunt game, we gained much priceless knowledge about environmental protection in the real world.” Therefore, the benefits of the game were increased motivation, enhanced collaborative learning activities, improved outcomes, maximized immersion, competition opportunities, and increased enjoyment (Liu, Tan, & Chu, 2009).

**Authentic Context Awareness**—contextual information can be used to characterize the situation of an entity, which can be a person, place, or physical object that is considered relevant to the interaction between a user and an application (Dey, 2001). The advantage of context-aware learning is to engage real learning experiences and improve learning effectiveness, especially in the real world (Cooper, 1993). A student wrote the following in his survey response:

Student 22: In the activity, I saw fiddler crabs waving fiddle claws and waterfowls looking for food beside the pond. I could also reach out to touch *Kandelia candel*. This activity not only allowed me to read webpage-based materials any time but also to watch biological creatures closely.

In the interview, a student stated that he was seldom exposed to nature. He thought that the learning activity allowed him to watch wild creatures and deepen his understanding. Therefore, context-aware learning enables students to gain authentic learning experiences and improve their cognition.

**Vivid Immersion**—immersion provides learners opportunities to learn by interacting with virtual objects, which, depending on the content, may enhance conceptual understanding of the content (Bricken & Byrne, 1993). A student wrote the following in his survey response:

Student 26: During the “Unexpected Encounter” activity, when I walked into the crab area, I could not see any *Uca lactea* (a species of fiddler crab). Through the m-AR function of the PDA, I could see a virtual *Uca lactea* waving its fiddle claws on the swamp that are not normally seen in the real world and even those that no longer inhabit the earth.

In the interview, a student said, “With the augmented reality tool (m-AR), I could see a virtual dragonfly perching on a stone.” On the discussion forum, a student said, “Although I could not watch even a single *Anas platyrhynchos* on the river, I could see a virtual one on the PDA screen by using the m-AR tool, which was very cool.” Therefore, immersive learning activity provides learners the opportunities to learn by watching virtual objects, which may enhance their conceptual understanding.

### **Perceived educational affordances**

**Skillful Application**—application is the use of new knowledge to solve problems in new situations by applying acquired knowledge, facts, techniques, and rules in different ways (Anderson & Krathwohl, 2001). The perceived educational affordance of application is to provide learning tools to develop student thinking skills, to analyze questions, to solve problems, to work cooperatively, and to share personal experience. The students noted the following in their survey responses:



Students 10 and 11: My classmate Eddy and I saw thousands of crabs marching on the sand. He asked me “Do you know approximately how many crabs are there?” I immediately counted the number of crabs within a square of 20 centimeters (twelve crabs) and estimated the area of this sand land (about 12 square meters). Later, I used the calculator on the PDA to determine that there were about 3600 crabs on this sand land.

In the interviews, the students said, “After completing our report and submitting it to our teacher, our teacher immediately graded our report and presented it to other classmates.” Therefore, the students could apply the skills for sharing information, discussing issues, completing common tasks, and cultivating problem-solving ability.

**Methodical Analysis**—analysis means to break material into its constituent parts and to determine how the parts relate to one another and to an overall structure or purpose (Anderson & Krathwohl, 2001). Methodical analysis helps students enhance their problem solving skills. A student noted the following in his survey response:

Student 8: We could not observe how bacteria decompose fallen leaves and how planktons eat organic substances. On the basis of our data and observations, we concluded at the end of our discussion that the interdependent relationship in the wetland should be as follows: The fallen leaves will first be decomposed by the bacteria in the water or mud and then absorbed by planktons, which mollusks, shellfish, shrimp, crabs, and fish feed on. Mollusks, shellfish, shrimp, crabs, and fish constitute the diet of various bird species.

According to the observations, students could learn how to analyze a problem and then form a conclusion. Therefore, the analytical process emphasizes students’ abilities to differentiate, organize, and attribute abilities.

**Creative Synthesis**—synthesis is combining elements and parts to form a whole. This involves the process of working with pieces, parts, elements, etc. and arranging and combining them in such a manner as to constitute a pattern or structure which was unclear or not explicit before (Bloom, 1956). Creation is to combine elements to form a coherent or functional whole, compiling information in different ways by combining elements in new patterns or proposing alternative solutions (Anderson & Krathwohl, 2001). A student noted the following in his survey response:

Student 32: The test results of our team were unsatisfactory. However, we were good at using the image capturing tool (m-Capture), audio recording tool, and editing tool (m-Notes) provided by the system, so our report was highly rated. With this report, our overall performance was not too much behind that of others.

In the interview, students stated that they utilized the editing tool (m-Notes) to integrate collected files into a vivid multimedia-based report comprising text, sound, graphics, and video. Therefore, the editing tool helps the skill of student to synthesize.

**Ubiquitous revision**—if every student is given sufficient time to learn and is instructed with proper teaching tactics, all students can achieve the same learning achievement (Bloom, 1968; Levine, 1985). Ubiquitous learning environment provides students many more opportunities to review course materials. A student noted the following in his survey response:

Student 7: I stored class handouts and teaching materials in the PDA and reviewed them while waiting for buses. These tools allowed me to review lessons at any time and any place, and they deepened my understanding and memory of the lessons.

In research observation, handheld learning devices offer advantages in portability, storage capability, and multimedia functions. Students usually reviewed learning materials stored in PDAs during leisure hours, thus increasing their familiarity with the lessons.

**Seamless Collaboration**—collaborative learning means that students learn together, share experiences, solve

common problems, and complete assigned tasks (Zheng, Ogata, & Yano, 2004). Through diverse learning tools in the ubiquitous learning environment, the students could synchronously and continuously complete a common task in a distant place. A student noted the following in his survey responses:

Student 7: The title of our team report was “How to restore wetlands?” Under the guidance of the teacher, Melody captured the image of bank-protecting mud slopes and government beautification efforts. Carol found on the Internet that the government is currently dismantling unused fish ponds, filling them, and then removing waste on the land so that native plants can grow on the wetlands and provide a living environment for animals. Becky reported that the education center in the Guandu Nature Park was established to promote environmental awareness and is effective for teaching citizens to preserve the ecological system. We concluded that promoting the concept of environmental protection and artificially restoring the natural environment are the most effective methods of restoring wetlands.

On the basis of the abovementioned data analysis, we conclude that our proposed ubiquitous learning environment and natural science course affords eight actual educational affordances: unconstrained knowledge accession, real-time evaluation, individuality, diverse interaction, arbitrary data collection, ubiquitous game play, authentic context-awareness, and vivid immersion. The students identified five perceived educational affordances: skillful application, methodical analysis, creative synthesis, ubiquitous revision, and seamless collaboration.

### The perceived degree of educational affordances

In the students’ perceived degree of educational affordances, the statistical results of the questionnaire is presented in Table 2 and illustrated in Figure 4.

Table 2. Statistical results of the questionnaire

Question	Yes Degree	Educational Affordances*
Do the learning tools help you to understand wetland ecosystems and environmental protection?	81%	Unconstrained Knowledge Accession
Do the learning tools enable you to participate in tests after finishing learning in a zone?	100%	Real-time Evaluation
Do the learning tools help you record personal learning portfolio?	75%	Individuality
Do the learning tools and course help you interact with teachers and classmates?	86%	Diverse Interaction
Do the learning tools enable you to record videos and photos anytime?	100%	Arbitrary Data collection
Do the learning environment and course enable you to play a game outdoors?	69%	Ubiquitous Game Play
Do the learning environment and course help you gain useful knowledge in a real context?	83%	Authentic Context-awareness
Do the learning tools enable you to watch virtual creatures in real world?	61%	Vivid Immersion
Do the learning tools help you solve the assigned problem?	89%	Skillful Application
Did you use the calculator in this course?	25%	Methodical Analysis
Does the learning environment help you finish the report and homework?	72%	Creative Synthesis
Do the learning tools help you review the course materials at any time and place?	58%	Ubiquitous Revision
Do the learning tools help your team finish team report?	83%	Seamless Collaboration

\*This field was concealed in questionnaire.

The statistical results reveal that the real-time evaluation was approved by all students (100%) because they concentrated on participating in tests to evaluate their outcomes. The educational affordance on arbitrary data

collection was also approved by all students (100%) because they employed the EULER to collect data in order to obtain good grades on their homework and reports. Those two results prove Webb’s (2005) argument: ICT provides pedagogical effects in promoting cognitive acceleration and facilitating data collection. The educational affordances on unconstrained knowledge accession, diverse interaction, authentic context-awareness, skillful application, and seamless collaboration were approved by more than 80% of the students because most students used EULER to acquire knowledge, exchange files with members, share their experiences with classmates, interact with teachers, observe real wildlife, and solve the assigned problem. The educational affordances on individuality and creative synthesis were also approved by 70%–80% of the students; those who did not approve did not use EULER to organize their personal schedules and felt that their products were not creative. The educational affordances on knowledge construction, interaction, context-awareness, collaboration, and individuality also prove the finding from Klopfer *et al.* (2002), Patten *et al.* (2006), and Churchill and Churchill (2008). The educational affordances on ubiquitous game play and vivid immersion were approved by only 60%–70% of the students because the other students felt that the course designer could add more interesting games to the course and that the PDA screen was small and unclear when viewed in direct sunlight. The educational affordance on ubiquitous revision was approved by more than half the students (58%); those who did not approve were used to reading textbooks when reviewing. The educational affordance on the methodical analysis was approved by only a few students (25%); the reason was that this course did not design any assignment that required a methodical analysis to solve a problem. Several students raised mathematical or natural problems and then found the solution by using the learning tools. The educational affordance on analysis proved the finding of Churchill and Churchill (2008).

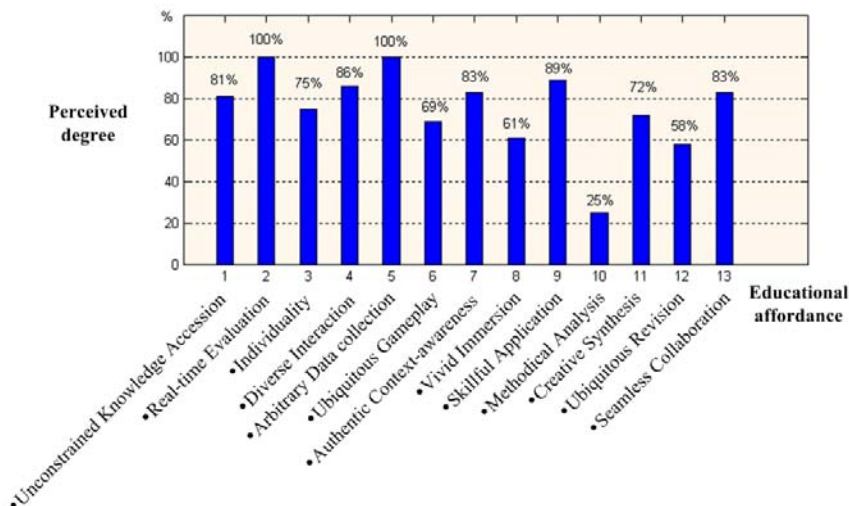


Figure 4. Bar chart representing the perceived degree of identified educational affordances

The organization of the aforementioned results and discussion and the relation between the identified educational affordances, learners’ actions, and educational goals are summarized in Table 3. Through the ubiquitous learning environment and natural science course offering the educational affordances, the learners’ actions enabled their learning to achieve the educational goals they pursued.

Table 3. Summary of educational affordances of a ubiquitous learning environment in a natural science course

Educational Affordances	Tools/Activities	Learner’s actions	Educational goals
<b>1. Actual affordances</b>			
Unconstrained Knowledge Accession	m-Loader, m-Browser, m-Capture, m-Notes, and m-Player/Understanding the ecology of wetlands	Access materials, read lectures, compile articles, and play medias	Construct knowledge, build cognition, and enhance comprehension

Real-time Evaluation	m-Test, m-Notes, m-Voting, and m-Portfolio/ Treasure hunt game	Evaluate outcome, examine homework, examine reports, present intend, and evaluate portfolio	Evaluate learning outcomes, and improve knowledge cognition
Individuality	m-Calendar, m-Portfolio, m-Browser and m-Player/ Understanding the ecology of wetlands	Organize personal schedule, save learning records, and manage personal portfolio	Perform individual activity, develop private portfolio, engage individualized learning experiences, accomplish learner-centered learning, foster self-management ability, foster good learning habits, and improve learning performance
Diverse Interaction	All tools/ All activities	Discuss issues, share information, present ideas, and present intent, and interact with virtual objects	Enhance peer interaction, increase motivation, improve outcome, improve human relationship, healthful psychology, improve learning efficiency, improve teaching quality, and develop thinking ability
Arbitrary Data collection	m-Loader, m-Capture, and m-Browser/ Understanding the ecology of wetlands and Wetland rescue	Collect videos, audios, images, articles and data	Foster data collection ability, build learning basis, develop investigation, and enhance learning cognition
Ubiquitous Game play	m-Browser, m-RFID, and m-Test/ Treasure hunt game	Retrieve context-aware materials, and play ubiquitous game	Increase learning interest, engage learning motivation, enhance learning interactivity, and improve learning outcomes
Authentic Context-awareness	m-RFID and m-Player/ Treasure hunt game	Retrieve context-aware data, play media, combine courses with real world, and observe wildlife behavior	Engage learning experiences, improve learning effectiveness, and construct authentic knowledge
Vivid Immersion	m-AR/ Unexpected encounter	Combine virtual and real world objects as well as provide spatial, temporal and contextual conceptualization	Improve understanding and enhance learning experiences
<b>2. Perceived affordances</b>			
Skillful Application	All tools/All activities	Access materials, browse materials, collect data, compile articles, play media, calculation, analysis data, present intend, organize schedule, manage personal information, discuss issues, share information, evaluate achievement, present ideas, retrieve context-aware materials, and compile reports	Apply information technologies for learning and foster problem-solving skill, exploring ability, and independent thinking ability
Methodical Analysis	Embedded calculator and analysis tool/ Wetland rescue	Collect data, observe wildlife, analyze data, and make a conclusion	Foster data analysis ability and explore new knowledge
Creative Synthesis	m-Loader, m-Capture and m-Notes/ Wetland rescue	Integrate learning objects into productions	Combine elements and produce creative products, and achieve self-satisfactory

Ubiquitous Revision	m-Loader, m-Player and m-Browser/ Understanding the ecology of wetlands	Browse learning materials, save learning materials, and review learning materials at any time and place	Increase familiarity with lessons, enhance learning experiences, and improve learning performance
Seamless Collaboration	m-Loader, m-Browser, m-Capture, m-Share, m-Messenger, Forum, and m-Notes/ Wetland rescue	Share information, share experience, complete a common task, and produce team reports	Increase peer interaction, engage motivation, improve outcome, improve human relationship, enhance healthful psychology, and find out social value of existence

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## Conclusions and future work

This study finds thirteen educational affordances divided into two categories. The ubiquitous learning environment and course provided eight actual educational affordances, which included unconstrained knowledge accession, real-time evaluation, individuality, diverse interaction, arbitrary data collection, ubiquitous game play, authentic context-awareness, and vivid immersion. The students' responses identified five perceived educational affordances, which were skillful application, methodical analysis, creative synthesis, ubiquitous revision, and seamless collaboration. Among these affordances, seven gained good approval (greater than 80%), four gained general approval (greater than 60% but lower than 80%), and two gained no-good approval (lower than 60%) from the students, implying that the educational affordances provided by the EULER and the natural science course gained major approval (average is 76%) from the students.

The educational affordances explicated in this study should be useful to teachers when they employ ubiquitous computing technology, rich educational resources, and diverse pedagogical tactics to improve the student learning effect and help students achieve their learning goals. Our future research will be dedicated to investigating the differences in educational affordances between different instructional environments and open courses using different learning tools, learning contexts, learning affections, theme-based activities, and instructional strategies.

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