Peng, H., Chuang, P.-Y., Hwang, G.-J., Chu, H.-C., Wu, T.-T., & Huang, S.-X. (2009). Ubiquitous Performance-support System as Mindtool: A Case Study of Instructional Decision Making and Learning Assistant. *Educational Technology & Society*, *12* (1), 107–120.

Ubiquitous Performance-support System as Mindtool: A Case Study of Instructional Decision Making and Learning Assistant

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ABSTRACT

Researchers have conducted various studies on applying wireless communication and ubiquitous computing technologies to education, so that the technologies can provide learners and educators with more active and adaptive support. This study proposes a Ubiquitous Performance-support System (UPSS) that can facilitate the seamless use of powerful new technologies in the school setting. In order to help the readers visualize these novel technologies in practice, we present one case study of a butterfly-ecology training course facilitated by the UPSS. The aim behind the case study is to inform the design and the development of context-aware ubiquitous computing system and its learning materials. The research inquiry centers around three themes: (1) the critical features to the data-driven decision making of teachers, (2) the perceptions of teachers and students to the UPSS, and (3) implementation issues. The results of the two rounds of formative evaluation indicate positive effects of the UPSS regarding motivation, interactivity, and effectiveness. In addition, teachers' attitudes and teachers' pedagogical approaches toward UPSS use are two key factors in the successful implementation of teaching with such innovative technology. This study can be a useful reference for those who are interested in conducting studies applying context-aware ubiquitous computing to educational contexts. Finally, this study presents suggestions and implications for future research and system development.

Keywords

Ubiquitous learning, Context awareness, Data-driven decision making, Performance-support system, Ubiquitous performance-support system

Introduction

In 2001, the United States government passed the *No Child Left Behind Act* (NCLB), which requires states to develop annual assessments of school and student progress that, as accumulated data, are to help educators improve the learning of all students. Similar to NCLB, policy that the government in Taiwan has established requires administrators and teachers to use data to help improve the quality of education on the island (Hwang, 2003). The educators are confronting complex sources of data from which the educators must make informed instructional decisions (Cagiltay, 2006; Hwang et al., 2008). These new expectations have placed heavy responsibilities on educators, who now are trying not so much *to modify* as *to re-conceptualize* educational decision making and who now, also, are simultaneously extending data to these newly re-conceptualized areas, ranging from resource allocation to instructional practices. As a result, educators need adequate performance support to facilitate this transition so that they can become successful in this new working environment.

Recent digitalization around the world has been proceeding toward wireless sensor networks, which embed computation and communication components into the environment. These devices detect certain aspects of the contexts of our daily lives, and provide personal support accordingly. Such technology has been called ubiquitous computing (u-computing). In the meanwhile, advances in these new technologies have led to a new research issue in education, that is, the issue of developing a novel learning environment so that students can learn in any place at any time. Moreover, with the help of context-aware (sensor) technology, learning systems can detect students' learning behaviors in the real world, and hence, students and educators alike can conduct more active and adaptive learning activities (Hwang, 2006). This learning scenario has been called context-aware ubiquitous learning (context-aware u-learning), which has gradually become a popular trend in education (Ogata & Yano, 2004; Hwang et al., In Press).

In recent years, several research projects have investigated various ways of applying these new technologies to education, and one of the chief goals of these studies has been to strengthen the technologies' capacity to provide active and adaptive support to real-world learning and training. By accounting for the functions of context-aware ubiquitous computing and interactivity, this study proposes a Ubiquitous Performance-Support System (UPSS) that can facilitate the seamless use of powerful new technologies in the school setting. This study also offers readers one case study that, based on this UPSS, can help them visualize these novel technologies in practice. The aim behind the case study is to inform the design and the development of context-awareness ubiquitous computing system and its learning materials. The research inquiry centers around three themes: (1) the critical features to the data-driven decision making of teachers, (2) the perceptions of teachers and students to the UPSS, and (3) implementation issues. Two rounds of formative evaluation are used to address the three inquiry themes. By presenting the process and the results of the research approach, this study can be a useful reference for those who are interested in conducting studies applying context-aware ubiquitous computing to educational contexts. Finally, this study presents suggestions and implications for future research and system development.

Backgrounds and Motivations

In a context-aware u-learning environment, students and educators can conduct real-world learning activities with adaptive supports from the learning system (Rodríguez & Favela, 2003; Ranganathan & Campbell, 2003; Kwon et al., 2005). Several researchers have demonstrated the benefits of such a learning environment in helping the learners to increase their problem-solving abilities in the real world (Jones & Jo, 2004; Hwang, 2006). For example, Ogata and Yano (2004) presented JAPELAS and TANGO, which educators have used to help students learn Japanese under real-world situations. The systems can provide learners with appropriate expressions according to different contexts (e.g., occasions or locations) via mobile devices (e.g., PDA, or Personal Digital Assistant). Rogers et al. (2005) conducted an experiment consisting of indoor and outdoor learning activities. According to the generalized findings, learners can use their observations to gather observation-drawn data, including voice data and image data, and learners can use wireless networks to gather related information from learning activities. Recently, Joiner et al. (2006) presented their studies on education-based use of context-aware devices and noted that the devices quickly offer students vocal statements about real-world conditions. In the meanwhile, Yang (2006) proposed a learning environment that stores resources according to a peer-to-peer (P2P) model and that functions to promote learning-resource sharing.

A performance-support system (PSS) functions to integrate resources into the execution of complex tasks. When these resources include electronic technology, the PSS becomes an electronic performance-support system (EPSS). Both Gery (1991) and Brown (1996) defined an 'EPSS' as technology that helps provide users with on-demand access to integrated information, guidance, advice, training, and tools that, in turn, promote high-level job performance with a minimum of support from other people. Therefore, the goal of an EPSS is to provide users with whatever is necessary to ensure performance and learning whenever a user engages in those activities.

The new computational paradigm, which includes ubiquitous computing and the context-aware feature, may create new possibilities for interactivity between humans and computers, and may provide users with supports that are more adaptive than are traditional EPSS supports. The UPSS combines digital and physical resources in novel ways; therefore, rather than see UPSS as merely a vehicle for delivering information, we can see it as a re-conceptualization of the whole work environment—an environment that is grounded in the fluid nature of support in the physical work environment and not in the static nature of formalized knowledge on isolated desktop computers. This concept matches the recent definition that Cagiltay (2006) assigns to EPSS in computer-based systems: "[EPSS] provides support at the moment it is needed (*right time*), and presents relevant (*right type*) and context-focused (*right amount*) information that a task performer needs, in a real work environment (*right place*)" (p. 94).

Also, the essence of the UPSS is similar to the essence of "mindtool" proposed by Jonassen (2000). Jonassen argues that, in a computer-assisted learning environment, all computer-based tools should be mindtools that function as intellectual partners of learners: in other words, mindtools should facilitate critical thinking and higher-order learning by adapting to the learners (p. 9). And by describing computer-based tools as intellectual partners, he asserts that a given responsibility should "fall to the partner who is better able to perform it" (p. 9). In intellectual partnerships, learners should be responsible for recognizing and judging patterns of information and then for organizing the information (tasks that humans perform better than computers), whereas computers should perform calculations and store and retrieve information (tasks that computers perform much better than humans).

The school environment that focuses on data-driven decision making has a distinct approach to the capabilities of humans and the capabilities of computers. In this regard, we can envision the possibility that school districts use technology-based solutions to make the handling of mass data more effective, whereas administrators and teachers are the ones to make final decisions based on the data collected from various sources.

A few studies have applied innovative mobile technologies or ubiquitous computing to student learning in fieldtrip settings (e.g., Chen, Kao, & Sheu, 2003), in museum settings (Hsi, 2003; Hall & Bannon, 2006), and in teacher-training settings (Seppälä & Alamäki, 2003). However, there is a dearth of research concerning the novel development and the novel deployment of context-aware ubiquitous computing in relation to data-driven decision-making processes for in-service teachers.

A Conceptual Framework of Data-driven Decision Making and Learning Assistant

Recognizing the importance of using a UPSS both for data-driven decision making and as a mindtool, we used the conceptual framework developed by Mandinach et al. (2006) to guide our design of this study's UPSS. This framework approaches data-driven decision making as a continuum that stretches from data to information and to knowledge and that addresses cognitive complexity in data where decision-making begins with raw data, transforms those raw data into information, and then ultimately transforms that information into actionable knowledge. The process implies that a successful UPSS needs to become a mindtool for administrators and educators if the UPSS is to perform a series of complex computational tasks before making the best instructional decision. This data-information-knowledge continuum rests on three types of skills: (1) collection and organization (*Data Level*), (2) analysis and summarization (*Information Level*), and (3) synthesis and prioritization (*Knowledge Level*) (Mandinach et al., 2006). Depending on the roles of decision makers and the scopes of school structure (i.e., classroom level, building level, and district level), the data used and the skills needed vary. Further, decision-makers will not always engage these skills in a linear, step-by-step manner. Instead, there will be iterations through the steps, depending on the context, the decision, the outcomes, and the interpretations of the outcomes. Figure 1 displays the procedures and the data types in this data-driven decision-making process.

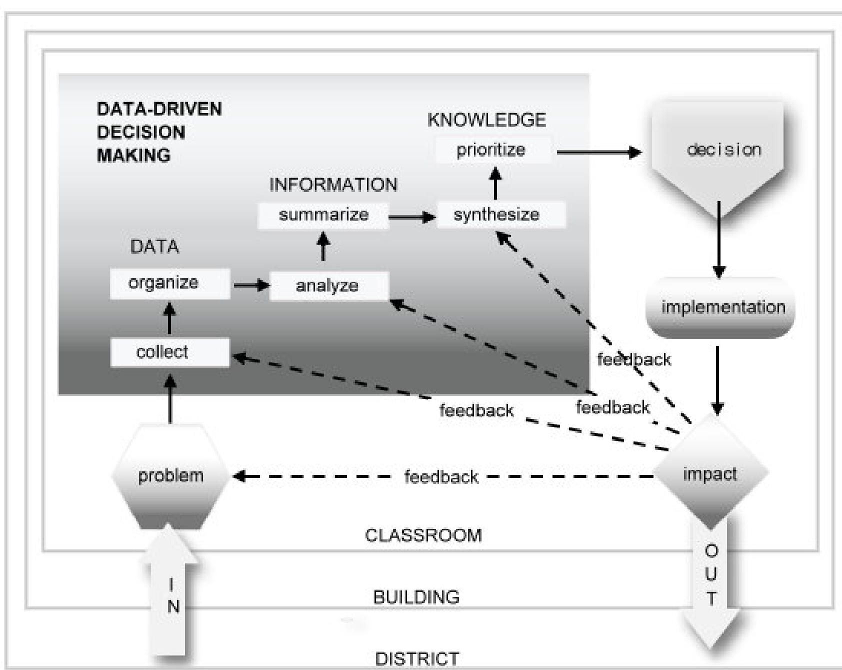

Figure 1. The conceptual framework for data-driven decision making (Mandinach et al., 2006)

UPSS in Practice: The Butterfly-ecology Course

The research team employed a systematic-design model (Dick, Carey, & Carey, 2005) that focuses on development-implementation-evaluation processes regarding both UPSS-environment development and UPSS-centered supporting materials. While developing the trial version of the UPSS, we conducted two experiments regarding the science course "Butterfly Ecology" at an elementary school in Taiwan: the first experiment took place from July to August 2007 and the second experiment, from January to February 2008. This particular school has been known for its butterfly-ecology training program and has been certified to regularly offer training programs for garden guides (Chu et al., In Press). Owing to the explorative nature of the study and the limited budget, we used two rounds of cost-effective evaluative strategies (e.g., expert review and two field trials) to provide an immediate tactical analysis of the function feasibility and implementation issues in the real-world setting. By presenting the process and the results of our evaluative strategies, we hope to provide a guide to others who are interested in applying context-aware ubiquitous computing to educational contexts.

To be more specifically, three themes were identified for analysis in this study.

1. What are important features of UPSS are critical to the data-driven decision making of teachers?
2. What are teachers' and students' perceptions of UPSS, with regard to motivation and learning?
3. What implementation factors are identified when considering the feasibility of integrating the UPSS into the existing curriculum?

The Context and the Participants

This study conducted two rounds of evaluations: round one included one instructional designer and one subject-matter expert (SME) and five elementary school students, and round two included nine science teachers and thirty elementary school students. These students took a special training program about butterfly-ecology gardens. The most challenging issue during the training was the mastery of observation and classification skills. To be sure, this process requires more than simply memorizing the appearance of plants or the facts from the textbook. In a traditional class in this field, a trainee teacher needs to deal with ten or more students and to develop the students' skills in observation and classification. With such a one-to-many approach, it is difficult for the trainee teachers to provide individual instruction and, in particular, to make informed decisions based on each individual student's feedback. Figure 2 shows one corner of the garden, which consists of 25 ecological areas with different plants and butterflies. The research team attached a radio frequency identification (RFID) tag containing key information on each target plant. Moreover, the knowledge database ran on a mobile device and enabled the students to tour a particular plant and the species of butterflies. While the students moved throughout the garden, via wireless communications, the UPSS displayed their learning portfolio consisting of students' locations and learning progress in relation to the garden, detected the information from the tags, and sent prompts to the students' mobile devices. Once the students entered their responses on the mobile device, the UPSS stores and aggregates the information from the embedded sensors connected to the networks (This process is considered as *Data Level* in our design framework).

In order to facilitate the trainee teachers' data-driven decision-making process, the research team also incorporated expert advice into the UPSS for problem structuring, decision support, analysis, and diagnosis. This advice existed in many forms that trainee teachers could invoke according to their needs. The advice involved an expert system that asked a trainee teacher questions and that then suggested the most appropriate procedure or step in response to the questions (*Information Level*). Or the advice involved an interactive expert system that used case-based reasoning or coaching to guide the teachers through decision-making processes (*Knowledge Level*). Table 1 tabulates the design concepts of the UPSS functions in the data-information-knowledge continuum.

Figure 2. The Butterfly ecology garden

Table 1. The UPSS functions in the data-information-knowledge continuum

Level	The UPSS Functions
Data	The UPSS actively collects and organizes students' data into learning portfolios (i.e., students' touring locations, their responses to the prompts provided by the UPSS) from the embedded sensors at the garden. The trainee teacher can make use of data in the fastest possible time and with a minimum of manually entered data.
Information	The UPSS summarizes and reports data to the trainee teacher. It focuses on approaches to analyzing and selecting needed information, on available resources, and on relating new knowledge to existing knowledge and experience.
Knowledge	The UPSS alerts the trainee teacher to available tools and resources that may be helpful under given circumstances. The UPSS also promotes the trainee teacher's contemplation skills by asking questions and by prompting the trainee teacher to identify a similar learning event on the basis of his or her own experiences.

The Trainee Teacher Interface

There are two types of UPSS interfaces: one is designed for the students and the other is for the trainee teachers. Figure 3 presents the UPSS trainee-teacher interface, which provides the trainee teachers with a tabulated interface that helps them not only maintain the course content and the knowledge base but also browse the profiles and the learning portfolios of the students. Each mobile device is equipped with an RFID reader, which can detect the signals sent from the RFID tags attached to each target object (e.g., the plant). The signals contain the unique identification codes of individual targets. As the students move around the garden, the UPSS can automatically detect, store, and aggregate the information as it moves from the embedded sensors and through the wireless networks. As shown in the right section of Figure 3, records in the portfolio database consist of several data fields on students' learning behaviors: locations, on-line learning materials browsed, on-line requests for help, notes taken, responses to questions, content of on-line discussions, duration of each observation, and each student's location-arrival time.

The Student Interface

Figure 4 displays the student interface on the mobile device. In the left screenshot, the UPSS guided the student to a corner of the butterfly garden and asked the student to find a plant called "Birthwort." After the student walked close to the plant, the UPSS displayed detailed information about the plant, as shown in the middle screenshot. In the right screenshot, the UPSS guided the student to the butterfly larva on that plant.

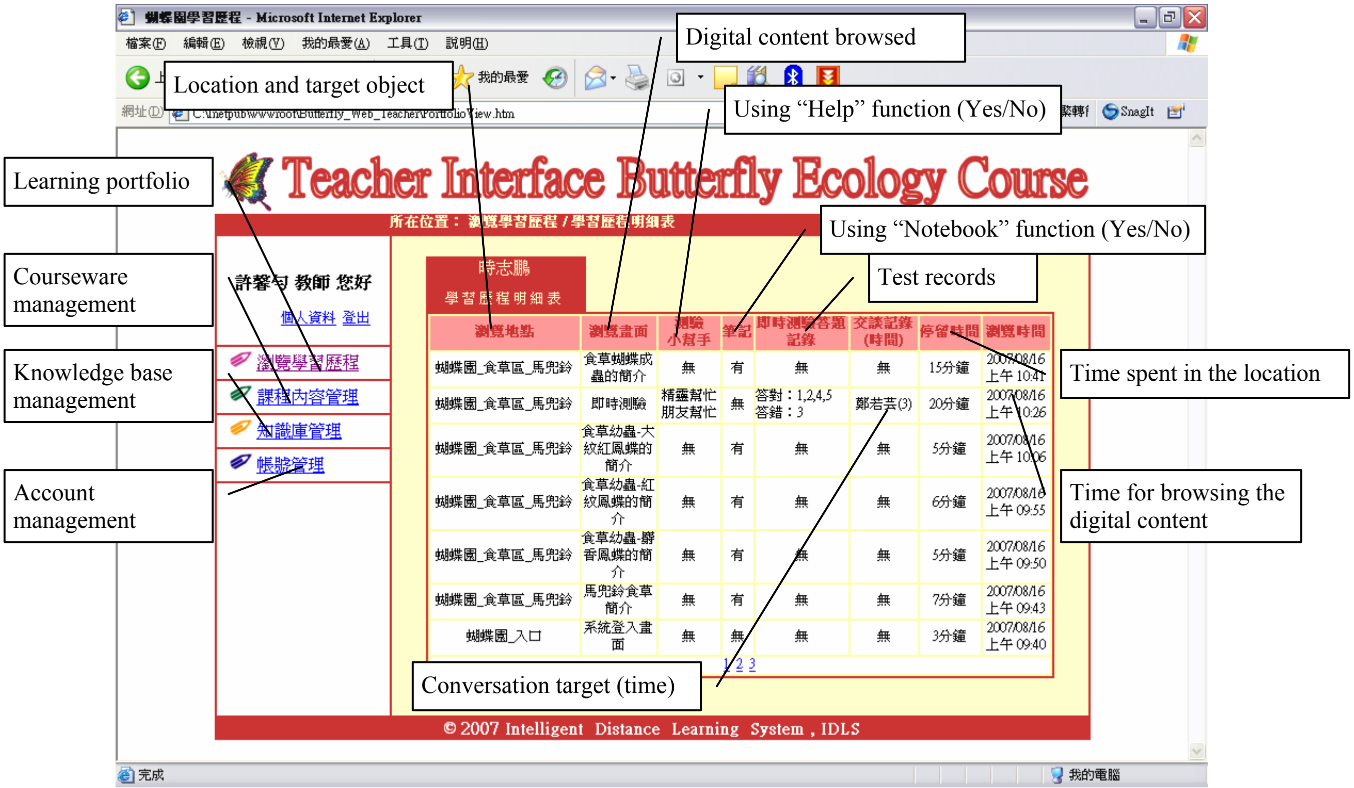

Figure 3. Teacher interface of the UPSS

Figure 4. Screenshots of the UPSS observation functions for butterfly ecology

Data Collection and Analyses

The system-development process was recursive, going through several phases of development, testing, and revision according to procedures in the two rounds of formative evaluations (see Dick et al., 2005): (1) expert review of both content and interface design by one expert in instructional design and by one SME expert, and (2) two field trials by potential users, including teachers and students. To address the three proposed inquiry themes, the research team collected both qualitative data and quantitative data from teachers and students over the two six-week implementation periods. The primary purpose of round one was to evaluate the accuracy and the currency of the training content and to evaluate the function feasibility of the UPSS (research inquiry one). The primary purpose of round two was to detect the implementation issues surrounding teachers' application of UPSS to school settings (research inquiry two and three). Therefore, the experts involved in round one were the ones who had designed the training content and had worked closely with the system programmers regarding the functions; the teachers and the students in round two were the potential users who might use the UPSS in their courses. At the end of the two experiments, we conducted surveys and interviews with the teachers and the students about their perceptions of the UPSS. The results informed our understanding of how the UPSS worked; and in turn, we sought to refine our system design.

In addition to the datasets that we collected from surveys and interviews, the UPSS simultaneously collected and organized data regarding the "physical" learning behaviors of individual students. These types of behavior concerned time, location, and student-system interaction (e.g., how, and after their observations, individual students responded to the system's prompts and instructions). The UPSS also enhanced students' reflections by comparing the students' responses with pre-defined learning behaviors or with expected answers (provided by the trainee teachers). A knowledge base embedded in the system rigorously calculated and prioritized critical misconceptions of individual students and helped enhance individual students' reflections.

For example, assume that UPSS is trying to guide the student to find "Birthwort" in the butterfly garden; nevertheless, the student walks to a wrong location and show a different plant to the system. UPSS will invoke the knowledge base to find the possible misconception, and then lead the student to make reflection by showing some hints and conducting the student to compare the differences between the two plants. Figure 5 shows the interface for supporting the student to make reflection while encountering difficulties in recognizing the target plants.

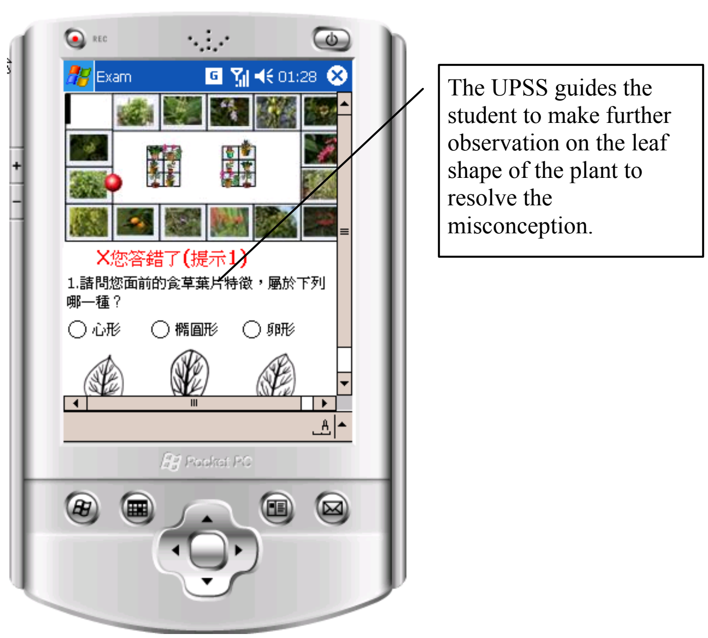

Figure 5. Screenshots of the UPSS for providing reflection supports

Round One: Expert Review

In round one, the draft version of the UPSS was reviewed by one instructional designer and one SME who operated outside the project and who had special expertise in the content area of the training. They were to comment on the accuracy and the relevance of the system and the training program. They also critiqued the function feasibility whose design rested on UPSS concepts and on the framework of data-driven decision making. This specific SME was also familiar with the target population and perhaps could provide insight into the appropriateness of the learning materials for the eventual performance context. The two experts actively observed five elementary students' use of the UPSS and engaged these students to contribute their ideas in the design process. Thereafter, the research team conducted in-depth interviews with these experts and the students. After collecting and summarizing the experts' data and the students' input, the research team made minor changes to the draft version of the UPSS and continued the second round of evaluation.

The review dimensions by the instructional designer and the SME included "Clarity" ("Are the training materials clear to the individual target students?"), "Effect" ("What effect does the instruction have on individual students' attitudes and on individual students' achievement of the objectives?") and "Feasibility" ("How feasible are the training materials in relation to the availability of resources such as time and context?"). Accordingly, the research team interviewed the trainee teacher and the SME with the following questions:
1. How long (in years) have you been training students in the butterfly-ecology program?
2. How many hours per week do you usually teach with the butterfly-ecology training materials? Do you use any instructional tools to facilitate your training process?
3. What is the average timeline that characterizes your preparation of a skilled guide for the butterfly-ecology garden?
4. Are there situations in your use of the UPSS that are unique or different from situations that arise in traditional training programs? If so, what are the situations?
5. What are a few important features that a UPSS should have? What tools or features might be added to the UPSS to make it better for your training? For instance, what types of activities or tools would you suggest to include in the UPSS in order to promote individualized learning?
6. What costs and benefits, if any, do you associate with using the UPSS for the training?
7. What is your perception of this alternative training mode's motivation of your students or the mode's enhancement of students' learning?

Furthermore, the students were interviewed with the following questions:
1. Have you attended a similar butterfly-ecology class before?
2. Was the butterfly-ecology program interesting?
3. How do you feel about using the UPSS for this training? Are there any differences between use of the UPSS and traditional training programs? If so, what are they?
4. What would you tell other students about the UPSS project?

Round Two: The Field Trial

The field trial used a learning context that closely resembled the learning context intended for the actual applications of both the UPSS system and related learning materials. One purpose of the round-two evaluation was to determine whether or not the post-review changes that the research team had made in both the system and the learning materials were effective. Another purpose was to determine whether or not the instruction was applicable to its intended context. A total of nine teachers and thirty elementary-school students participated in the field-trial rounds. In round two, the research team (1) interviewed nine teachers regarding both the integration of the UPSS into their science course and their perceptions of the benefits or the limitations therein, and (2) asked thirty students to fill out a survey regarding their experiences using the system. Here are the questions that the research team interested:
1. What are the differences between your use of the UPSS and your regular teaching practices?
2. What, if any, teaching benefits do you attribute to your use of the UPSS, particularly regarding teaching-load dimensions, students' motivation, and learning effectiveness?
3. Do you anticipate any costs that may arise from school-based use of the UPSS?
4. Will you try the UPSS for your science class in the future? If so, what pedagogy will you use? If not, why not?
5. Will you recommend the UPSS either to teachers or for subjects outside the natural sciences?

Results

After collecting the data from the two rounds of evaluations, the research team examined usability, student motivation, student learning, and classroom implementation issues, as shown in the following subsections.

Issues of Motivation, Management, and Effectiveness

Expert Review

Two experts were interviewed following the round one evaluation. Expert one (a science teacher, coded E1) had five years of experience in conducting the butterfly course, and Expert two (a science teacher, coded E2) had eight years of experience therein. When asked to comment on the differences between the ubiquitous learning environment and the traditional training process, the teachers voiced similar points of view: the teachers stated that both themselves and students were greatly benefited the mobile-learning environment in terms of motivation, manageability, and effectiveness.

For example, in relation to the "motivation" aspect, E1 stated, "It is obvious that the use of mobile devices can motivate the students. The multimedia materials are very attractive." She particularly favored the interactive-learning program: "In contrast to the traditional instructions given by the teacher, the students seemed to be happy while interacting with their mobile devices, which enhanced their motivation levels in the training." Further, E2 mentioned the "continuous concentration" of the students that manifested itself while the mobile device guided them during the learning process. He stated, "It is amazing that the students concentrated on the learning activities for a longer time than I ever expected."

As to the "manageability" aspect, E1 and E2 agreed about the benefits of the UPSS. E1 stated, "With this innovative UPSS system, we can browse the learning process of individual students. This would allow me to keep track of the real-world learning status of each student." E2 stated, "By recording every action and the paths of the students, the computer helps review their learning activities, and this significantly helps adjust the learning on the basis of the UPSS-collected data."

When asked about the functionality of the UPSS-provided guidance, E1 positively regarded the "effectiveness" aspect. E2 responded in kind: "The mobile device can correctly guide [students to] or hint at the learning paths and can, therefore, provide adequate learning content to students. It works like a tutor for each student, and I think most of the students would benefit from this UPSS system." Thus, it is reasonable to conclude that both the trainee teachers and the students considered the UPSS useful.

Student Feedback

There were two major sources of students' feedback: one was from the round one and the other was from the round two. In round one, five students, coded as student one (S1), S2, S3, S4, and S5, were selected for one-to-one semi-structured interviews. At the time, all these students were fifth graders and were eleven years old. They had taken a basic course concerning butterfly ecology. The chief purpose of the interview was to elicit UPSS-related responses and suggestions from the students after they had experienced the trial version of UPSS. All the interviews were recorded on a digital recorder, and all the data presented in this paper were then analyzed and translated by the authors.

When asked to discuss the differences between the UPSS and the traditional training process, the five students variously characterized the UPSS as an "interesting," "interactive," or "effective" learning assistant. For example, S1 found the UPSS "interesting and interactive" in comparison with the traditional training; S1 stated, "Unlike traditional training processes by teachers, the UPSS is more interactive because it shows every detail, which motivates my learning." He favored the interactive learning program: "I can go over the learning path repeatedly with the mobile device, rather than ask repetitive questions to the teachers. This flexibility has relaxed me in the learning process." S2 raised similar points: "The mobile device guides my observation of butterfly ecology step by step, and this makes me feel like I have a patient tutor who, on the side, reduces the learning pressure." The above responses indicate that the UPSS can provide friendly interface and a friendly learning environment. It is worth noting that, according to both S4 and S5, their use of the mobile device enabled them to access data when needed, a function that heightened their interest in the course.

As to the "effectiveness" perspective, all the students viewed the UPSS positively. For instance, when asked about how the learning-guidance function worked, four students (S1, S2, S3, and S4) noted the immediacy and the convenience of the system. S3 commented, "The mobile device can be an accurate guide or can suggest a learning path, and this makes me feel like I have a teacher beside me. I would prefer learning with this system to learning with teachers." Thus, it is reasonable to conclude, also, that the UPSS had a positive effect on the motivation of these students.

In round two, thirty students were asked to fill out the after-project survey. The three dimensions surveyed in this stage are *students' prior knowledge and skills in technology and butterfly ecology*, *experiences of learning*, and *students' overall impression of the unit*. The items of these dimensions were presented on a 5-point Likert scale, ranging from "strongly disagree" (1 point) to "strongly agree" (5 points). The results demonstrated students' positive perceptions of the learning unit. Table 2 shows the results of this field trial of this learning unit.

Table 2. Results of the field trials (N=30)

Dimensions and evaluation items	**SA** N (%)	**A** N (%)	**NE** N (%)	**D** N (%)	**SD** N (%)	**Mean score**
Part I. Prior Knowledge and Skills in Technology and Butterfly Ecology						
I observed the plants and butterflies in the butterfly-ecology garden before the teacher introduced this learning unit.	17 (56.7)	10 (33.3)	3 (10.0)	0	0	4.47
I used the personal digital assistant (PDA) before this learning unit.	2 (6.7)	6 (20.0)	5 (16.7)	13 (43.3)	4 (13.3)	2.63
I used a digital camera for butterflies before this learning unit.	11 (36.7)	14 (46.7)	5 (16.7)	0	0	4.20
I searched the Internet for information on butterflies.	5 (16.7)	7 (23.3)	9 (30.0)	3 (10.0)	6 (20.0)	3.07
My teacher used multimedia (e.g., images or videos) in class before this learning unit.	15 (50.0)	12 (40.0)	3 (10.0)	0	0	4.40
Part II. Learning Experiences						
I enjoy observing butterflies because of their attractive appearances.	7 (23.3)	12 (40.0)	7 (23.3)	4 (13.3)	0	3.73
I enjoy observing butterflies because I enjoy a natural life.	6 (20.0)	16 (53.3)	5 (16.7)	3 (10.0)	0	3.83
I enjoy observing butterflies because I can gain natural knowledge.	5 (16.7)	12 (40.0)	10 (33.3)	3 (10.0)	0	3.63
I was less motivated by my teachers' tour and lectures than by the illustrations and the guidance of the UPSS during this learning unit.	19 (63.3)	8 (26.7)	3 (10.0)	0	0	4.53
I tried to search information via the UPSS in this learning unit.	4 (13.3)	10 (33.3)	8 (26.7)	8 (26.7)	0	3.33
I think I have gained knowledge with the guidance of the UPSS in this learning unit.	11 (36.7)	8 (26.7)	9 (30.0)	2 (6.7)	0	3.93
I felt that using the UPSS made it convenient to observe butterflies in this learning unit.	15 (50.0)	15 (50.0)	0	0	0	4.50
I felt that my learning with the UPSS was easy in this learning unit.	16 (53.3)	14 (46.7)	0	0	0	4.53
I was more motivated in my discussions with classmates when I was using the UPSS than when I wasn't using the UPSS in this learning unit.	8 (26.7)	11 (36.7)	6 (20.0)	5 (16.7)	0	3.73

Dimensions and evaluation items	SA	A	NE	D	SD	Mean score
	N (%)	N (%)	N (%)	N (%)	N (%)	
Part III. Overall Impressions						
I have learned about the function of PDAs in this learning unit.	12 (40.0)	15 (50.0)	3 (10.0)	0	0	4.30
I have learned by observing through the UPSS in this learning unit.	10 (33.3)	18 (60.0)	2 (6.7)	0	0	4.27
I have learned about butterflies in this learning unit.	7 (23.3)	18 (60.0)	5 (16.7)	0	0	4.07
I feel that my interest in butterflies has grown since I completed this learning unit.	11 (36.7)	14 (46.7)	5 (16.7)	0	0	4.20
I will try to search for more information on butterflies after the class.	4 (13.3)	14 (46.7)	7 (23.3)	5 (16.7)	0	3.57
I felt that learning via the UPSS was much more interesting than learning via my teacher's tour and lectures.	16 (53.3)	14 (46.7)	0	0	0	4.53
I am satisfied with learning with the UPSS.	17 (56.7)	13 (43.3)	0	0	0	4.57
I felt that it is easier to learn with the UPSS (one student per PDA) than with my teacher's tour and lectures (one teacher with many students).	12 (40.0)	18 (60.0)	0	0	0	4.40
I think I can learn more with the UPSS than with my teacher's tour and lectures.	15 (50.0)	11 (36.7)	4 (13.3)	0	0	4.37
I think I am more comfortable learning with the UPSS than with my teacher's tour and lectures.	9 (30.0)	16 (53.3)	5 (16.7)	0	0	4.13
I think I am more motivated to learn with the UPSS than with my teacher's tour and lectures.	12 (40.0)	16 (53.3)	2 (6.7)	0	0	4.33
I will recommend this learning unit to other classmates.	9 (30.0)	12 40.0	6 (20.0)	3 (10.0)	0	3.90

SA = Strongly agree, A = Agree, NE = Neutral, D = Disagree, SD = Strongly disagree

The survey also asked how students felt about using the UPSS in the learning unit. Twenty-nine out of thirty students expressed that they had enjoyed using the UPSS and the personal digital assistant (PDA) for butterfly observation. For example, most students found use of the UPSS to be motivating because the system allowed for more self-paced learning and for more comparisons with the teacher's tour and lectures. Two students liked the convenience of immediate information retrieval, while one student mentioned that the system would provide personal guidance based on his inquiries. Only one student mentioned a technical problem (e.g., disconnection, and double-clicking for correct answers) that had hampered his learning.

Implementation Issues

In round two, the research team conducted one-to-one semi-structured interviews with nine teachers, who were coded as teacher 1 (T1) to teacher 9 (T9) and who had used the UPSS in their classes. All these teachers were trained in the sciences subject, and the teachers' years of teaching experience varied from five to sixteen years.

From the teacher interviews, the research team found that teachers' attitudes toward and teachers' pedagogical approaches toward UPSS use are two key factors in the successful implementation of teaching with innovative technology. With regard to the teachers' attitudes, most teachers had positive attitudes toward UPSS use and were willing to adopt it in their future teaching practices. Round-two findings were similar to round-one findings: these teachers agreed on the advantages of higher student motivation, as well as the individualized and adaptive supports resulting from teachers' adopting the UPSS. For example, they mentioned that learning with UPSS created many possibilities that were not easily achieved in the traditional learning environments. Some of these possibilities were (1) students' better access to mobile computers and to online resources and (2) reduced constraints relative to time or location (T3, T6, T8, and T9). Meanwhile, teachers believed that learning activities with the UPSS could help engage students in learner-centered activities seamlessly from one physical location to the next: part of this seamlessness stemmed from the UPSS's powerful ability to transfer data from the ecology garden to the computer lab and vice versa. Another strength of the UPSS lies in its data-collection features, its learning-portfolio features, and step-by-step expert advice which are automatically stored and aggregated through sensors and networks (T2, T3, T4, T5, T6, and T9). Indeed, T3 mentioned that "these contextual data are particularly useful for individualized or supplementary instruction after the learning activity, and these data can be another eye for the teacher." However, two teachers (T8 and T9) contended that they might not have time to create a UPSS-related learning activity because of tight schedules, particularly regarding the time constraints imposed by term exams. T9 doubted that some teachers at school have enough background knowledge of, or experience with, mobile computers to teach with such advanced technology; for example, many teachers had never used a personal digital assistant. Such feedback helped the research team confirm that, before successful implementation takes place, teachers must undergo sufficient technology training and must have access to handy materials—all grounded on sound learning theories and the features of context-aware ubiquitous computing.

These teachers believed that the UPSS can be implemented in many disciplines—such as the natural and pure sciences, the social sciences (e.g., tours of historical sites), and museum education—as long as the implementation takes place under student-centered pedagogical approaches, such as situated learning, inquiry- or problem-based learning, and collaborative learning. For instance, T4 described a learning scenario anchored around a theme of cultural or historical relics. He expected his role to be that of either a guide or a facilitator, and he expected to promote opportunities in which his students could initiate and control their own learning. Furthermore, he suggested that teachers who adopt not standard tests but innovative technology such as a UPSS should consider instructional goals and should accompany the technology with alternative assessment methods, such as portfolio evaluations, tokens, or group competition. In this way, he stated, the teachers could evaluate students' learning processes and learning outcomes. He added, "The UPSS collects rich data that the teachers should not overlook."

Conclusions

The advance of computer and network technologies has encouraged researchers to conduct various learning activities with mobile devices and wireless communication. This paper proposes a ubiquitous performance-support system (UPSS) that can facilitate the seamless use of powerful new technologies in school settings. On the basis of innovative approaches, we developed a ubiquitous-learning system for a butterfly-ecology course by systematic-design approach to refine the system and its supporting materials. By engaging in two rounds of design, implementation, analysis, and re-design, we have been able to refine both our curriculum and the UPSS environment prior to conducting formal randomized experimental trials in the future.

After the two rounds of evaluations, several parts of the design (e.g., step-by-step expert advice for teachers to generate reports based on students' portfolio data) have remained relatively unchanged from the initial implementation because our analysis indicated that these parts were successful in meeting our objectives. Other parts of the design have changed on the basis of feedback from round one. For example, we increased the number of tacit clues embedded in the UPSS to ensure continuous engagement of high-performance students in materials provided in the curriculum.

The results of formative evaluations reveal that the experts and students had positive perceptions of the UPSS in relation to motivation, interactivity, and effectiveness; in addition, both of the experts agreed that the mobile device's learning guidance (in the context of the real-world garden) was essentially helpful to the students. These reactions point to the effectiveness of this innovative training approach. Furthermore, as indicated in round two, the UPSS, because of its data-driven decision-making functions, enabled teachers to keep track of the students' learning status as well as facilitated the teachers' individualized instruction. Overall, these findings promote further refinement of and experimentation with UPSS as a training modality that can help teachers enhance students' motivation. These data are promising but not conclusive about the UPSS's educational value. By examining the fact that students found the UPSS readily usable and the learning experiences motivating, we also found weaknesses in the design, particularly from a graphical and curricular perspective. For example, teachers need more support for implementing this UPSS into their curriculum. As a result, we proposed a rigorous training program of professional development for teachers. The program functions, in part, to familiarize teachers with a constructivist pedagogical approach that enables students to actively and collaboratively explore the domain knowledge.

In traditional training settings or classrooms, teachers usually have to use their judgment or tests to gauge students' learning processes and learning outcomes after an experiment. Under such conditions, teachers often overlook much of the valuable contextual information; moreover, teachers must store and analyze this information in order to create individualized supports that, by accurately reflecting students' actions, enhance them. In the round-two interviews, the teachers confirmed the advantages of using context-aware ubiquitous computing as a mindtool (the data-collection and data-driven tool): such computing helped the teachers focus on decision-making practices. This finding also has an important implication for researchers: context-aware ubiquitous computing can serve as an objective yet unobtrusive data-collection tool depicting students' learning processes, whereas tests or surveys capture a much smaller wedge of the spectrum of students' learning, especially when students are engaged in an innovative-technology learning environment.

In conclusion, we assert that the innovative system proposed in this study can benefit teachers, students, as well as researchers. Future studies may examine the relationships between learner perceptions and learner usage of the UPSS and learners' overall satisfaction, in a larger scale, with longer experiment periods. Also, it may be interesting to explore the teachers' perceptions of using UPSS and their instructional strategies as implementing the UPSS into their existing curriculum.

Acknowledgements

This study is supported in part by the National Science Council of Taiwan, the Republic of China, under contract numbers of NSC95-2520-S-009-009, NSC NSC 97-2631-S-024 -002, and the Taiwan Ministry of Education (project title: ATU Plan of the National Chiao Tung University and Ministry of Education, Taiwan, R.O.C.).

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