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From Virtual Environments to Physical Environments: Exploring Interactivity in Ubiquitous-learning Systems

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ABSTRACT
Computing devices and applications are now used beyond the desktop, in diverse environments, and this trend toward ubiquitous computing is evolving. In this study, we re-visit the interactivity concept and its applications for interactive function design in a ubiquitous-learning system (ULS). Further, we compare interactivity dimensions and corresponding interactive functions of web-based learning systems with ULS, and we offer a technical framework for a successful incorporation of interactive functions into ULS. To enhance the ease-of-use and the overall effectiveness of this framework, each of the four panels of experts assessed its own interactive-function term: learning needs, instructional necessity, mobile-interface design, or programming difficulty. Last, this study presents the best practices of a learner-centered ULS and discusses the panel experts' reviews of interactive functions in such a learning environment, along with suggestions for future research.

Keywords
Ubiquitous computing, Ubiquitous learning, Context aware, Interactivity

Introduction

Interactivity is a central concern in the design of such mediated instructional settings as computer-assisted instruction (CAI), computer-assisted learning (CAL), and online-learning environments. Educational researchers believe that the quality of interaction, in addition to the content, determines the effectiveness of instructional practice and individual discovery (Sims, 1997) and, therefore, determines the quality of learning (Draves, 2000). Rapid progress in the development of mobile and wireless technologies has created new computational environments that will shape how people learn and work and that will, of course, change interactive types of learning. Various embedded and invisible devices, as well as the corresponding software components, have been both developed and connected to the Internet wirelessly. This new Internet-ready environment has been called a ubiquitous-computing environment, in which *virtual and electronic* resources underlie the portable wireless devices that help users navigate the *real and surrounding physical world*. Another feature of the ULS is the use of wireless-communication resources with sensors, so that the communication system can sense user information and environmental information in the real world and can provide personalized services in return. This feature is often known as "context aware" computing (Hwang, 2006).

Learners are no longer facing a desktop machine in the relatively predictable classroom environment. Rather, they have to deal with diverse devices (mobile ones and fixed ones) to explore diverse interfaces and to use them in diverse environments. The new computational paradigm, which includes the ubiquitous-computing feature and the context-aware feature, may create new possibilities for interactivity among learners, computers, and surroundings. As more and more people perceive the application of ubiquitous computing to be a leading teaching-learning technology in education, the interactivity concept will need to undergo continuous re-examination and updating in terms of operational guidelines for interface designers, instructional designers, and programmers.

In this study, we re-visit the interactivity concept and its applications for interactive-function design in ULS. Further, we compare interactivity dimensions and corresponding interactive functions of web-based learning systems with ULS, and we offer a technical framework for the successful incorporation of interactive functions into ULS. To enhance the ease-of-use and the overall effectiveness of this framework, each of four panels of experts assessed its own interactive-function term: learning needs, instructional necessity, mobile-interface design, or programming difficulty. Last, this study provides best practices of a learner-centered ULS and discusses the panel experts' reviews of interactive functions in such learning environment, along with suggestions for future research.

Interactivity in Learning Systems

Interactivity has been defined differently, each definition reflecting the perspectives of the group using it. Weller (1988) describes interactivity as an event or a process that occurs when a learner actively adapts to information being presented by a form of technology that, in turn, adapts to the learner. Merrill, Li, and Jones (1990) argue that interactivity in learning involves real-time dynamics and mutual give-and-take between an instructional system and a learner—especially in relation to exchanges of relevant information. Apparently, these definitions address interactivity's accounting for the relationships between a learner and the instructional content presented by either an instructor or an instructional system. As the role of collaborative learning (learning together with one's peers) is gaining prominence in modern learning environments, this study discusses, as well, the interaction between the learner and his or her technology-facilitated peers.

Interactive Types and Interactive Dimensions

Moore (1989) was the first to attempt to identify three interactive relationships associated with distance learning: learner-content (e.g., information) interactions, learner-instructor interactions, and learner-learner interactions. However, Hillman, Willis, and Gunawardena (1994) argue that Moore's three relationships do not account for interactions that occur between learners and the technologies that deliver instruction or content, and the three researchers, therefore, suggest a fourth type: learner-interface interactions. The researchers claim that successful interaction is highly dependent upon how comfortable a learner feels working with the delivery medium, through which a learner can interact with content, the instructor, and other learners.

In the past, what enabled ubiquitous computing to take off was the existence, from the earlier e-learning phase, of millions of desktop computers, many already connected to the Internet. Those are the foundations on which ubiquitous computing stands. We can clearly see that ubiquitous computing inherits the interaction types of online learning. However, what differentiates ubiquitous computing from the online environment is the former's seamless infusion of the online environment into the physical environment. The latest computers are no longer confined to a box on a desk, and they can be personal and portable, to be used when necessary. The information in the physical and the electronic environments creates a *context* for the interaction between humans and computational services. Dey and Abowd (2000) have defined "context" as any information that characterizes a situation related to the interaction between users, applications, and the surrounding environment. This remarkable infusion and mobility creates new interaction types. Peng, Chou & Chang (2007) propose a fifth type, *learner-context* interaction, representing the interactivity wherein a system adapts to the needs of individuals in order to fulfill those needs. Context can be the location, the identity, or the state of people, groups, computational objects, and other physical objects. However, in the latest modern context-aware applications, researchers often concentrate on an application's gathering of and the application's use of implicit environment-sensed input. They also propose a sixth interaction type—*learner-self* interaction, which previous literature often overlooked. This type represents the interactivity through which a system promotes intra-personal management and reflections (see figure 1).

Chou (2003) conducted a sweeping literature review of the interactivity concept and of the concept's implications for interactive function design in communication technology, computer-assisted instruction, distance learning, and web systems. On the basis of this review, Chou proposes nine dimensions to support interactivity in these systems. We re-organize these nine interactive dimensions, in consideration of both the roles that learners and the roles that systems play in the interaction, as listed in Table 1.

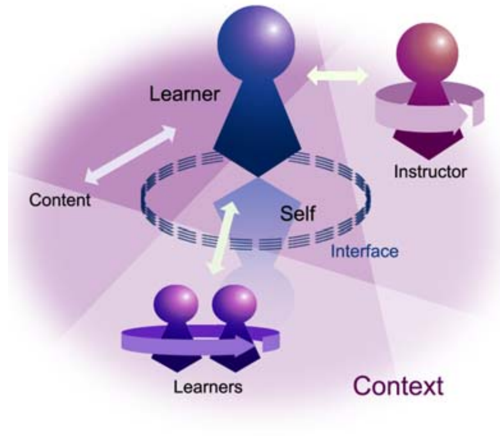

Figure 1. The concept of a learner-centered ULS (Peng, Chou, & Chang, 2007)

Table 1. The interactivity dimensions and their definitions

Role	Interactivity dimension	Definition
Learners' determination to make a choice in the system	Choice	The amount of the multimedia type of information that users (learners and instructors) have access to. This dimension also covers the non-information options that learners can choose.
	Non-sequential access of choice	Learners can access information in a non-linear way.
	Monitoring of information use	The system can collect data on the learners themselves, their selections, their use of information, and so on. The learners can monitor information regarding them.
	Facilitation of inter-personal communication	There are different ways in which learners can communicate with each other asynchronously or synchronously.
	Ease of adding information	Learners can add information to the system, to the content, and so on.
System provides services that react to learners' actions	Responsiveness to learners	The system responds to learners' requests in a non-delayed fashion.
	Personal-choice helper	Information helps learners make better choices relative to instructional content.
	Adaptability	System adapts the interaction process and the exchange of information to individuals.
	Playfulness	Information arouses learners' curiosity and encourages learners to entertain themselves.

* Adapted from Chou (2003).

Technical Framework of ULS

We believe that the interactive dimensions of ULS share the characteristics of the interactive dimensions of online-learning systems; therefore, extending Chou's technical framework, we propose the following interactive dimensions of ULS: *learner-interface, learner-self*, *learner-content*, *learner-instructor*, and *learner-learner* interaction, and *learner-context* interaction. We arrived at this list of interactive functions by modifying the list from Chou's study and by combining the latter list with our experiences with ULS design. The *learner-interface* interaction type—the foundation for the other types—includes four interactivity dimensions and nine corresponding interactive functions that can be included in any system. This inclusion grants learners efficient and easy access to the system anytime and anywhere as needed. The *learner-self* interaction type includes three interactivity dimensions and five interactivity functions, all of which help learners to keep monitoring their learning progress. The *learner-content* interaction type helps learners understand richer, deeper, and more individualized learning materials, while the *learner-instructor* and the *learner-learner* interaction types are designed to facilitate inter-personal communication in the virtual learning community. The *learner-context* interaction type can collect environmental feedback to expand learning experiences beyond time and location: for example, interactive filming can adapt a dramatic plot to learners' passive interaction (i.e., pulse measuring), so as to keep the learners' interest at a high level.

Table 2 displays both the new interactive types (i.e., learner-self interaction and learner-context interaction) and a modified version of previous interactive functions in learning-themed web systems. The interaction types can help educators and designers both depict a sweeping canvas, as it were, of ubiquitous learning and categorize relationships between or among components essential to the learning process—consisting of the first-person learner, the system/interface, content, other learners, the instructor, and the context. So that interactions are successful, interactive technical functions need to be incorporated into the ULS. The list displayed in Table 2, however, is not exhaustive, but it certainly can serve as a starting point for later expansion.

Table 2. The framework for interaction types, interactivity dimensions, and interactive functions in ULS

Types of interaction	**Dimensions of interactivity**	**Interactive functions in ULS**
Learner-interface	• Choice • Non-sequential access of choice • Responsiveness to users • Monitoring of information use	Fixed-frame (menu) design Site map Keyword search and database search Online problem diagnostics Software downloading Online registration Grade-status tracking and assignment-completion tracking
Learner-self (Intra-personal)	• Choice • Non-sequential access of choice • Monitoring of information use	Diary and reflective journal Calendar and reminder Task-list Clock
Learner-context	• Choice • Non-sequential access of choice • Responsiveness to learner • Adaptability	Global positioning system (GPS) Sensor (e.g., humidity) Bio-feedback
Learner-content	• Choice • Non-sequential access of choice • Responsiveness to users • Adaptability • Personal-choice helper • Ease of adding information • Playfulness	Links to related learning materials Multimedia presentation (text, graphics, animation, audio, etc.) Online quiz for self-evaluation Push media Individualized learning database Frequently asked questions (FAQ) Online help on content User guidance through system Study guidance Learners' contributing to learning materials Educational games/jokes
Learner-instructor	• Facilitation of interpersonal communication • Ease of adding information	Emails to instructors/web master Bulletin board systems (BBSs) Chat rooms/messaging Online voting and survey system Comments on the course, site, instructor, etc.
Learner-learner	• Facilitation of interpersonal communication • Ease of adding information	Class roster Emails to other learners Bulletin board systems (BBSs) Chat rooms/messaging

* Adapted from Chou (2003).

Evaluation of the Technical Framework

The Panel Experts' Reviews

To enhance the ease-of-use and the overall effectiveness of this framework, each of four panels of experts assessed its own interactive-function term: learning needs, instructional necessity, mobile-interface design, or programming difficulty. The four panels, together, consisted of a total of seven members: four were learners (graduate students who had used ULS) and three were instructional designers (each with more than four years of experience designing ULS). The researchers asked them to evaluate each interactive function's necessity relative to the support learning and instruction in an ideal, generic ULS. For each function, panel experts expressed their belief as to whether each function is a "must have," a "should have," a "nice to have," or an "OK if missing." The researchers then conducted in-depth interviews with these seven experts to reach a consensus on instructional necessity and learning needs.

A total of six members, consisting of three interface designers and three programmers, each with more than five years experience programming ULS, were asked to evaluate how difficult it would be to implement individual interactive functions in an ideal ULS. They were asked to check one of the four boxes for each function: "easy," "not difficult," "difficult," and "very difficult." The researchers conducted in-depth interviews with these six interface designers and programmer to identify any consensus on the programming difficulty and the mobile-interface design of each interactive function.

A Scenario of ULS

A ULS features a variety of interactions that are essential to learning and teaching. Despite both the novelty of ULS and the limitations of current technologies, research teams have implemented and studied some related experiments and applications. On the basis of the interactivity dimensions and the interactive functions listed in the above technical framework, we used two scenarios—one concerning a water-quality evaluation (Vahey & Crawford, 2002) and the other concerning the geometric shapes in everyday life (Peng & Chou, in press)—to describe the best practices related to the integration of pedagogical practices into context-aware ubiquitous-computing contexts. These two scenarios are to help experts visualize the interactive functions that support learning and instruction and to help the experts predict the difficulty levels of mobile-interface design and programming for these interactive functions. In this scenario, university students who were studying environmental engineering were divided into groups. The students took their handhelds and probes to a nearby stream where each student took measurements at different points along the streambed. The students combined their data by beaming or aggregating from the embedded sensors connected to the networks. On the basis of the collected datasets, the system calculated and guided the students to the nearest appropriate location so that they could finish their tasks within the shortest time. When students returned to the classroom, they used their handhelds to graph and analyze the combined datasets, and the students presented their conclusions to other students (see Figure 2). A copy of the panel-review form (for evaluating learning needs) is provided as Appendix 1.

Tables 3 to 8 show the results of the panel experts' reviews of each interactive function. When considering learning needs and instructional necessity, none of the seven experts checked "OK if missing" for any of the interactive functions. This result means that experts agreed on using all the interactive functions, if possible, to facilitate the interactions in an ideal ULS. From the perspectives of mobile-interface design and programming, some functions are easily incorporated into ULS. These functions include task-lists (learner-self interactive function), class rosters (learner-learner interactive function), and online voting and survey systems (learner-instructor interactive function). However, certain functions that deal with learner-content (e.g., individualized instruction) and learner-context (e.g., bio-feedback) interactive dimensions are difficult to program, especially when those adaptations that systems need provide individualized services that react to learners' actions. In order to highlight both pedagogical and technical issues, we re-organized the interactive functions on the basis of the following two criteria: (1) the researchers prioritize "must have" interactive functions (i.e., functions that satisfy learning needs and instructional purposes) as evaluated by learners and instructional designers; and (2) the researchers keep "easy" or "not difficult" interactive functions (i.e., functions that satisfy interface-design purposes and meet the programming difficulty level) as evaluated by mobile-interface designers and programmers. The following sections discuss the results of the panel evaluation, along with suggestions from in-depth interviews.

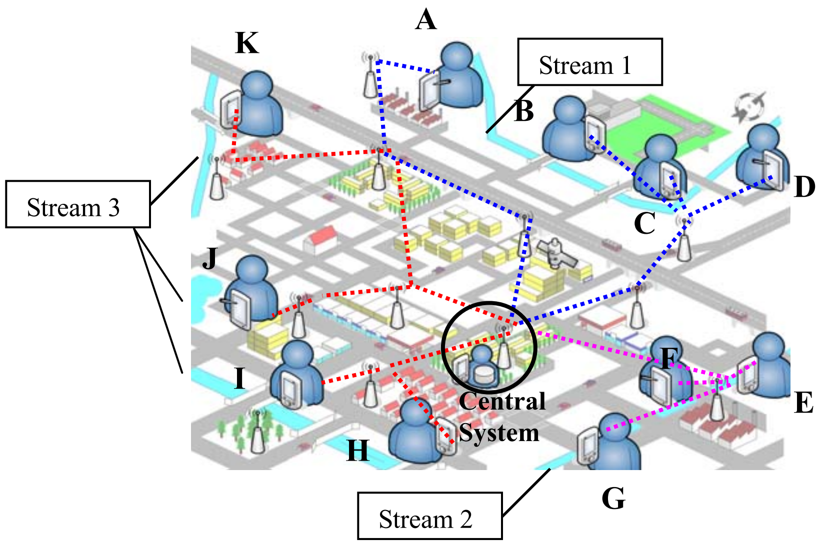

Figure 2. The scenario of water quality evaluation

Table 3 presents the panel experts' reviews of interactive functions in the learner-interface dimension. For this dimension, which is the foundation of the other interactive dimensions, the learners and instructional designers agreed that two functions were "must have" (i.e., site map and online problem diagnostics) and that two functions were "should have" (i.e., software downloading and online registration). Disagreements arose concerning "grade-status tracking and assignment-completion tracking" and "keyword search and database search"; however, instructional designers considered these two functions to be necessary for instructional purposes. Although the panels' instructional designers considered the "fixed-frame (menu) design" a "nice to have" function, one mobile-interface designer suggested the removal of this function:

> Owing to the limited space in handheld devices, learners can use only one application at one time; I don't think they need a fixed-frame design to aid their navigation through the ULS.

One programmer suggested the removal of the "software downloading" function:

> In a ULS, learners can connect to the Internet to download files; there seems no need to create an extra application specifically for downloading the software.

Table 3. Panel experts' reviews of interactive functions in the learner-interface dimension

Interactive functions in ULS	Learning needs	Instructional necessity	Mobile-interface design	Programming difficulty
Site map	Must have	Must have	Difficult	Not difficult
Online problem diagnostics	Must have	Must have	Difficult	Difficult
Keyword search and database search	Must have	Should have	Not difficult	Not difficult
Grade-status tracking and assignment-completion tracking	Should have	Must have	Not difficult	Not difficult
Software downloading	Should have	Should have	Easy	Not difficult
Online registration	Should have	Should have	Not difficult	Not difficult
Fixed-frame (menu) design	Should have	Nice to have	Difficult	Not difficult

Table 4 presents the panel experts' reviews of the interactive functions of the learner-self dimension. The learners and the instructional designers were consistent in identifying two "must have" functions and two "should have" functions, while the mobile-interface designers and the programmers stated that creating these functions was "easy" or “not difficult.” However, two mobile-interface designers expressed their concerns regarding the “diary and reflective journals”:

> In order to facilitate learners’ reflective thinking, most web-based learning systems include diaries or reflective journals; however, learners are not used to typing too much text into their handhelds. Instructional designers perhaps should make maximum use of mobile devices for inputs: tools such as handwritten texts and audio- or videotaping of events.

Table 4. Panel experts’ reviews of the interactive functions of the learner-self dimension

Interactive functions in ULS	**Learning needs**	**Instructional necessity**	**Mobile-interface design**	**Programming difficulty**
Task-list	Must have	Must have	Easy	Easy
Calendar and reminder	Must have	Must have	Not difficult	Easy
Clock	Should have	Should have	Easy	Not difficult
Diary and reflective journal	Should have	Should have	Not difficult	Easy

Table 5 presents the panel experts’ reviews of the interactive functions of the learner-context dimension. The learners and instructional designers identified one “must have” function (Global positioning system) and one “nice to have” function (bio-feedback). A disagreement arose concerning “sensor,” with instructional designers voicing the following idea:

> Besides making the maximum use of mobile devices, instructors should consider seamlessly integrating tools, such as a sensor for humidity testing, into teaching practices. The phrase “seamless use” refers to tools that strengthen the value of current instruction, and sensors seem to be capable of distinguishing ubiquitous learning from web-based learning.

Both mobile-interface designers and programmers noted that the functions of the learner-context dimension were either “difficult” or “very difficult” in relation to certain needed adaptations—those requiring complex, high-level programming techniques that are not as mature as the existing techniques in the web-based learning systems.

Table 5. Panel experts’ reviews of the interactive functions of the learner-context dimension

Interactive functions in ULS	**Learning needs**	**Instructional necessity**	**Mobile-interface design**	**Programming difficulty**
Global positioning system (GPS)	Must have	Must have	Difficult	Difficult
Sensor (e.g., humidity)	Should have	Must have	Difficult	Difficult
Bio-feedback	Nice to have	Nice to have	Difficult	Very difficult

For learner-content interactive functions listed in Table 6, the instructional designers and the learners agreed that eight functions were “must have” and that one was a “should have.” Disagreements arose concerning “learners’ contributing to learning materials” and “educational games/jokes”. Of these two functions, educational games/jokes belonged to the playfulness dimension and acquired the rating “nice to have.” The mobile-interface designers and the programmers described the top five interactive functions as “not difficult” but described functions such as “study guidance” and “online quiz for self-evaluation” as “difficult”, because these functions require system’s active responsiveness to learners and certain adaptability needed to meet personal needs. Last, the panel experts commented that the bandwidth and the screen size in multimedia presentations may hinder the interaction.

Table 7 presents the panel experts’ reviews of the interactive functions of both the learner-instructor dimension and. For learner-instructor functions, the learners and instructional designers identified one “must have” function (i.e., email to instructor/web master), and two “should have” functions (i.e., Comments on the course, site, instructor, etc. and BBS). Take “chat rooms/messaging” as an example: the instructional designers preferred synchronous communicative channels, while learners preferred not having to chat with the instructor in a synchronous fashion. In addition, disagreements arose concerning “online voting and survey system,” with some panel experts considering it a means of promoting equal student participation (thus, an enhancer of learner-instructor interaction) and other panel experts considering it a redundancy of other two-way communication channels (e.g., chat rooms, emails and messaging). Concerned that the slow text input might have hindered the learner-instructor interaction, the mobile-interface designers thus suggested that voice mail, text messaging, or phone communication could take advantage of mobility and immediacy. In a similar vein, the programmers suggested that instructional designers should use the existing application connect learners through the Internet—for example, through Skype for its synchronous chatting; thus, the programmers suggested removing the functions of "BBSs" and of "online voting and survey system," even though these functions were not difficult to program.

Table 6. Panel experts' reviews of the interactive functions of the learner-content dimension

Interactive functions in ULS	Learning needs	Instructional necessity	Mobile-interface design	Programming difficulty
Links to related learning materials	Must have	Must have	Not difficult	Not difficult
Individualized learning database	Must have	Must have	Not difficult	Not difficult
FAQ	Must have	Must have	Not difficult	Not difficult
Online help on content	Must have	Must have	Not difficult	Not difficult
User guidance through system	Must have	Must have	Not difficult	Not difficult
Push media	Must have	Must have	Not difficult	Difficult
Study guidance	Must have	Must have	Difficult	Not difficult
Multimedia presentation	Must have	Must have	Not difficult	Not difficult
Learners' contributing to learning materials	Should have	Must have	Difficult	Difficult
Online quiz for self-evaluation	Should have	Should have	Difficult	Difficult
Educational games/jokes	Should have	Nice to have	Not difficult	Difficult

Table 7. Panel experts' reviews of the interactive functions of the learner-instructor dimension

Interactive functions in ULS	Learning needs	Instructional necessity	Mobile-interface design	Programming difficulty
Email to instructor/webmaster	Must have	Must have	Difficult	Difficult
Chat rooms/Messaging	Should have	Must have	Difficult	Not difficult
Comments on the course, site, instructor, etc.	Should have	Should have	Difficult	Easy
BBSs	Should have	Should have	Difficult	Not difficult
Online voting and survey system	Nice to have	Should have	Easy	Not difficult

Finally, Table 8 presents the panel experts' reviews of the interactive functions of the learner-learner dimension. The instructional designers and the learners agreed that the functions of the learner-learner interaction such as email and chat rooms or messaging were all necessary, while the programmers stated that such interactive functions were not difficult. Mobile-interface designers again proposed that alternative channels besides text input can be useful for instant learner-learner interactions. The programmers suggested removing the function of "BBSs" because there has been no BBS package for handhelds.

Table 8. Panel experts' reviews of the interactive functions of the learner-learner dimension

Interactive functions in ULS	Learning needs	Instructional necessity	Mobile-interface design	Programming difficulty
Emails to other learners	Must have	Must have	Difficult	Easy
Chat rooms/Messaging	Must have	Must have	Difficult	Not difficult
Class roster	Should have	Must have	Easy	Easy
BBSs	Should have	Should have	Difficult	Not difficult

These results can help the designers of new ULS consider not only learning-needs issues and instructional-design issues but also the interactive functions that must or should be included in ULS. To this end, the designers will consider interaction types, interaction goals, resources (including budgets, personnel, and resources), and required programming techniques. For systems already in use, the results can serve as a checklist guiding formative evaluations or as a benchmark for a ULS. In this way, the results can help ensure great interaction quality. Depending on the objectives of the ULS, designers can consider weighing the ratings from the learners (the learner-centered approach) or the ratings from the instructional designers (the instructor-centered approach). Regarding ULS design, we suggest that designers first incorporate the interactive functions marked "must have," "easy," and "not difficult" into the design and that the designers then consider including the functions marked "should have," "easy," and "not difficult" into the design. Only with sufficient personnel and resources can designers consider including all other functions into the ULS design. A modified technical framework after the panel-expert reviews is included in Appendix 2.

Based on the scenario described above, Table 10 presents a must-have, learner-centered version consisting of 15 essential and minimum interactive functions that will ensure a successful ULS. The asterisk beside "Global positioning system (GPS)" identifies the programming level as "difficult"; however, we decided to keep this function for two reasons: first, the instructional designers pointed out that the effects of GPS on ULS are "indispensable"; and second, these GPS effects distinguish ULS from other web-based learning systems.

Table 10. A "must-have, learner-centered" ULS design

Types of interaction	Interactive functions in ULS
Learner-interface	Site map
	Grade-status tracking and assignment-completion tracking
	Keyword search and database search
Learner-self	Task-list
	Calendar and reminder
Learner-context	Global positioning system (GPS)*
Learner-content	Links to related learning materials
	Individualized learning database
	FAQ
	Online help on content
	User guidance through system
	Multimedia presentation
Learner-instructor	Email to instructor/webmaster
Learner-learner	Emails to other learners
	Chat rooms/Messenger

Several Concerns regarding the Technical-framework Use

For future study, researchers and practitioners should address several concerns regarding the current technical-framework use.

1. The conceptual structure of the technical framework

Owing to the novelty of education-applicable ubiquitous computing, this study's proposed technical framework serves an awareness-raising purpose, which, in turn, serves as a conceptual step toward effective ULS design. We believe that effective design should derive from re-organizing the concepts and the theories underlying various applications and strategies. Therefore, the scenario provided in the current study presents an "ideal ULS" that emphasizes wireless-communication resources with sensors. Such ULS system enables the communication system to sense user information and environmental information in the real world and, by these means, to provide personalized services to each user (Hwang, 2006). However, we also recognized that different scenarios may yield different consideration results and different evaluation results.

2. The unilateral view of interactivity

Most of the literature reviewed in this study takes the perspectives of communication theories and learning theories. In classical communication theories and learning theories, interaction is a state between a sender and a receiver, and between them lie messages that can usually be categorized into source and feedback. A good interaction may be reached by continuous modifications of source messages and feedback messages. A unilateral way of thinking can help us better analyze each individual interaction and can further simplify the interactive functions. For instance, in analyses of a learner-centered ULS design, the "other side" can be only interface, content, context, instructor, or the learner himself or herself in multiple interactions, regardless of whether the learner is a message receiver or a message source. We believe that such a unilateral view can, in some way, serve as a foundation for concurrent interactions among multiple users.

3. The rationale of selection of panels

The experts to be included in the study need to be highly experienced in ubiquitous-computing interface design, in ubiquitous-computing programming, and in applications of ubiquitous-computing interface power to teaching and learning. As the ULS is still at its infancy stage, we decided to have only experienced users contribute insights into the system-development process. In spite of this, we suggest that future studies consider including some non-experienced users after the ULS becomes available.

Similar to the function of a Likert scale, the panels specify level of agreement to the criteria items. The ratings (e.g., must-have and nice-to-have) can be flexible in use, as our intentions are to find the potential of a specific interactive function to be implemented in a given scenario. We expect that future studies' use of this strategy can successfully combine the pieces of the puzzle, as it were, to yield an encompassing picture of ULS. Owing to the explorative nature of the study, the results of expert reviews have provided sufficient expert validity (over 85% agreement in every interactive dimension), indicating that these experts have expressed similar concerns and have reached a certain consensus regarding ULS-design issues. Our in-depth interviews with the current study's experts have helped resolve some of these debates.

Conclusion

Extending from Chou's technical framework (Chou, 2003) for web-based systems, this study suggests that ULS designers should integrate combinations of technical functions into ULS designs and that these combinations should account for learning needs, instructional design, mobile-interface design, and programming difficulty.

Future research efforts may focus on the relationships between technical interactions and cognitive interactions among learners: for example, the relationships that arise when instructors use questioning and answering to engage learners. The correct use of this technical framework and its interactive functions to promote cognitive interactions poses a challenge for instructional designers.

Another potential research area lies in the connection between the use of interactive functions and learning outcomes, since greater numbers of interactive functions do not necessarily guarantee better learning. The proposed technical framework does not address the appropriate evaluative strategies, which would strengthen both the learning process and learning outcomes. In this regard, the following research question merits considerable attention: Do technically interactive functions that characterize a ULS help enhance learners' cognitive interactions and, therefore, enhance the learners' learning achievement?

Future studies may examine not only the relationships between learner perceptions and learner usage of these interactive functions but also learners' overall satisfaction with a particular ULS system. Two operational questions would ground these types of studies: (1) Are students aware of the interactive functions provided by the ULS, and do the students like those functions? And (2) do students appreciate learner-centered or instructor-centered interactive dimensions and functions that are incorporated into a specific ULS?

Studies exploring the factors concerning teachers' pedagogical beliefs may account for the successful integration of ULS into schools. For example, in a case study, Liu (2007) found that even though the teacher held positive beliefs regarding student-centered instruction and innovative technology, the teacher's instructional practices were significantly restricted by his or her teacher-centered approach. This inconsistency between instructional beliefs and practices resulted in the teacher's willingness to apply wireless technology but in the teachers' inability to bring it into full play. The interactive functions suggested by our technical framework combine an instructor-centered approach and a learner-centered approach, and the following research questions can be of interest: (1) In terms of the learner-centered approach and the instructor-centered approach, what are teachers' perceptions of the use of interactive functions? And (2) do technically interactive functions that characterize a ULS enhance or hinder teachers' instructional practices?

This study proposes a technical framework whose significance rests on the framework's ability to carry out two tasks: (1) to extend interactive dimensions and interactive functions from web-based learning systems to ubiquitous learning systems, and (2) to identify currently available ubiquitous computing techniques that helps fulfill the conditions of this extension. In order to increase the effectiveness of instructional ULS design, experts from instructional perspectives and technical perspectives divided into four panels and identified indispensable interactive functions. This technical framework serves as an initial step toward meeting the goals of effective design.

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Appendix 1. The panel expert review form for learning needs

A ubiquitous-learning system features a variety of interactions which are essential to learning and teaching. Consider your role as a learner who uses interactive functions in the ubiquitous-learning system; check the most appropriate descriptions to explain your learning needs in such system.

Types of interaction	Interactive functions in ULS	Learning needs			
		Must have	Should have	Nice to have	No need to have
Learner -interface	Fixed-frame (menu) design				
	Site map				
	Keyword search and database search				
	Online problem diagnostics				
	Software downloading				
	Online registration				
	Grade-status tracking and assignment-completion tracking				
Learner-self (Intra-personal)	Diary and reflective journal				
	Calendar and reminder				
	Task-list				
	Clock				
Learner-context	Global positioning system (GPS)				
	Sensor (e.g., humidity)				
	Bio-feedback				
Learner-content	Links to related learning materials				
	Multimedia presentation (text, graphics, animation, audio, etc.)				
	Online quiz for self-evaluation				
	Push media				
	Individualized learning database				
	Frequently asked questions (FAQ)				
	User guidance through system				
	Study guidance				
	Learners' contributing to learning materials				
	Educational games/jokes				
Learner -instructor	Emails to instructor/webmaster				
	Bulletin board systems (BBSs)				
	Chat rooms/messaging				
	Online voting and survey system				
	Comments on the course, site, instructor, etc.				
Learner -learner	Class roster				
	Emails to other learners				
	Bulletin board systems (BBSs)				
	Chat rooms/messaging				

Suggestions and comments:

Appendix 2. A modified technical framework with the panel-expert reviews

Notes: This version has removed three functions “fixed-frame (menu) design”, “software downloading”, and “BBSs”.

Types of interaction	Interactive functions in ULS	Learning needs	Instructional necessity	Mobile-interface design	Programming difficulty
Learner -interface	Site map	Must have	Must have	Difficult	Not difficult
	Online problem diagnostics	Must have	Must have	Difficult	Difficult
	Keyword search and database search	Must have	Should have	Not difficult	Not difficult
	Grade-status tracking and assignment-completion tracking	Should have	Must have	Not difficult	Not difficult
	Online registration	Should have	Should have	Not difficult	Not difficult
Learner-self (Intrapersonal)	Task-list	Must have	Must have	Easy	Easy
	Calendar and reminder	Must have	Must have	Not difficult	Easy
	Clock	Should have	Should have	Easy	Not difficult
	Diary and reflective journal	Should have	Should have	Not difficult	Easy
Learner -context	Global positioning system (GPS)	Must have	Must have	Difficult	Difficult
	Sensor (e.g., humidity)	Should have	Must have	Difficult	Difficult
	Bio-feedback	Nice to have	Nice to have	Difficult	Very difficult
Learner -content	Links to related learning materials	Must have	Must have	Not difficult	Not difficult
	Individualized learning database	Must have	Must have	Not difficult	Not difficult
	FAQ	Must have	Must have	Not difficult	Not difficult
	Online help on content	Must have	Must have	Not difficult	Not difficult
	User guidance through system	Must have	Must have	Not difficult	Not difficult
	Push media	Must have	Must have	Not difficult	Difficult
	Study guidance	Must have	Must have	Difficult	Not difficult
	Multimedia presentation	Must have	Must have	Not difficult	Not difficult
	Learners’ contributing to learning materials	Should have	Must have	Difficult	Difficult
	Online quiz for self-evaluation	Should have	Should have	Difficult	Difficult
	Educational games/jokes	Should have	Nice to have	Not difficult	Difficult
Learner -instructor	Email to instructor/webmaster	Must have	Must have	Difficult	Difficult
	Chat rooms/messaging	Should have	Must have	Difficult	Not difficult
	Comments on the course, site, instructor, etc.	Should have	Should have	Difficult	Easy
	Online voting and survey system	Nice to have	Should have	Easy	Not difficult
Learner -learner	Emails to other learners	Must have	Must have	Difficult	Easy
	Chat rooms/messaging	Must have	Must have	Difficult	Not difficult
	Class roster	Should have	Must have	Easy	Easy