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A FRAMEWORK OF THREE LEARNING ACTIVITY LEVELS FOR ENHANCING THE USABILITY AND FEASIBILITY OF WIRELESS LEARNING ENVIRONMENTS*

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ABSTRACT

The most recent advances in information technology have brought wireless communication and mobile devices to education. The wireless technology enhanced classroom (WiTEC) integrates a wireless local area network, mobile learning devices, and client-server architecture to support instruction and learning activities. This article introduces a framework that involves three learning activity levels—learning functions, learning episodes, and learning flows—as a basis for designing an integrated system that supports various types of learning activities in WiTEC. A teacher can use this system to generate new learning flows before class and to implement them during class. A two-stage evaluation was conducted in three 6th grade classes to investigate the usability and feasibility of the proposed system. The participating teachers indicated that the use of the three learning activity levels eased the burden of preparing, implementing and reviewing instruction and learning activities.

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INTRODUCTION

In the last decades, many technological innovations have been applied in the classroom, such as radio, television, film, video, and computers. Most of these media technologies (with the exception of computers) support one-way communication and have had only isolated, marginal influences on how and what children learn in school, despite the early championing of their revolutionary educational potential (Roschelle, Pea, Hoadley, Gording, & Means, 2000). Even computers have not yet fundamentally affected classrooms, in part because they are heavy, have messy wires, and are operated via a keyboard and mouse. Most applications of wireless and mobile devices for learning, on the other hand, use devices with small displays, such as personal digital assistants (Chang, Sheu, & Kao, 2003; Chen, Kao & Sheu 2003; Hsi, 2003) and portable computers (Bannasch, 2001) to support outdoor or mobile learning. Indeed, ubiquitous educational technologies can greatly expand the range of activities that students can undertake (Tinker, 2001).

Our previous work focused on the development of the Wireless Technology Enhanced Classroom (WiTEC) that integrates a wireless LAN, mobile learning devices (MLD), an electronic whiteboard, a resource and class management server, and an interactive classroom server to support everyday activities unobtrusively and seamlessly in the classroom. Among these devices is the interactive learning center, which is installed on an MLD, as the student's client program, supports a learner's interactions with peers and the instructor, as well as interactions within content-rich contexts without barriers. The interactive instruction center, which is operated through an electronic whiteboard as the teacher's client program, assists the teacher in acting as mediator, supporter, facilitator, and/or guide during everyday classes. The resource and class management server manages teaching and learning resources and activities, and the interactive classroom server keeps track of individual operating processes and coordinates interactions between the teacher and students as well as among students. The WiTEC system enhances productive teacher-student and peer-peer interactions (Liu, Wang, Liang, Chan, & Yang, 2002) and enables the teacher and students to concentrate more on teaching and learning itself and less on tedious tasks. It helps the teacher to monitor each student's learning for further guidance, to engage students in a variety of learning activities, and to facilitate collaboration among students. The WiTEC system empowers teachers and students to apply technologies to a variety of traditional and innovative learning and teaching activtities (Liu, Wang, Liang, Chan, Ko, & Yang, 2003). Its features effectively support teachers and students in numerous instructional and learning activities that are difficult to implement in ordinary classrooms, such as the Jigsaw model of collaboration or project-based learning (Liu et al., 2002, 2003).

Gay, Stefanone, Grace-Martin, and Hembrooke (2001) noted that "not every teaching activity or learning community can or should successfully

integrate mobile computing applications" (p. 273), and Tuckman (2002) asserted that "the nature of the instructional model is the critical element in technology-enhanced instruction" (p. 261). The WiTEC system has been established and tested in real classroom settings, but some issues remain to be explored further. Different class structures, content areas, and pedagogical models all influence the productivity of instructional activities in WiTEC. Whether the WiTEC system can achieve its anticipated goals and effectively facilitate student learning depends on how the teacher and students use it. Guiding class members in appropriately using the system and integrating relevant technologies into everyday teaching and learning activities are crucial to its success (Ko & Liu, 2001). Compared with conventional and even technology-rich classrooms, most teachers and students still view the WiTEC as an innovative technology. Developing appropriate tools for guiding effective implementation is key to the progress of WiTEC from the research stage to practical use.

Gifford and Enyedy (1999) presented a theoretical framework for Computer Support for Collaborative Learning (CSCL) called the Activity Centered Design (ACD) model to help course designers and teachers design collaborative learning activities for the classroom. ACD provides a unifying theoretical perspective for designing CSCL lessons that help learners perform socially formulated, goal-directed activities through the use of mediating materials and social structures. Adopting the ACD model, Brecht, Chung, and Pea (2002) proposed the ClassSync Modeling Language (CML) for mapping the design of an activity onto its implementation in a wireless, handheld classroom. CML allows authors and teachers to construct activities by creating assemblages of three components—performers of actions, units of information, and an interaction network. Once the activity is created, the teacher can implement the activity in runtime in the ClassSync system. However, whether the CML can be effectively and efficiently used in instructional practice has not yet been determined.

This article presents a framework that involves three learning activity levels—learning flow, learning episode, and learning function—to support the design and implementation of instruction and learning activities in a wireless learning environment. An integrated system comprised of an instructional support subsystem, a learning support subsystem, and a collaboration mechanism supported by learning functions was developed by adopting the framework to support teaching and learning activities in WiTEC. The system not only provides flexibility of activity design, enabling the teacher to arrange and implement such activities, but it is also extendible. The system developer can add new features to meet practical needs.

A two-stage evaluation of three 6th grade classes using the proposed system to support collaborative learning was conducted to investigate the usability and feasibility of the enhanced WiTEC system.

THREE LEARNING ACTIVITY LEVELS

Learning activities in a classroom can be designed, analyzed, and evaluated at three different levels of scale: learning flow, learning episode, and learning function. The progress of a learning activity can be represented as a learning flow composed of several learning episodes supported by multiple learning functions. A learning function is a specialized mechanism for facilitating learning activities, such as content presentation or content transmission. A learning function is defined in terms of three elements: *action*, *content*, and *participants*. For example, the content presentation function allows a teacher to present particular content to students. The action in this example is "to present" and the participants are the teacher and the students. A learning episode is the basic unit of a learning or instructional activity, such as lecturing, holding a group discussion, or creating reports. Each episode is supported by a small set of learning functions. For example, an episode of "lecturing" might involve the presentation of content and the use of technological annotation functions through which the teacher presents content and annotates it. A function may support several learning episodes; for instance, the content presentation function can support both a teacher's lecturing and presentation by student groups. A learning flow is a complete sequence of learning episodes organized to meet a specific learning goal. For example, a learning flow might be composed of four episodes: a teacher's lecturing, student group work, student presentation of group work and student peer voting. A learning flow may have branches to allow the skipping of, or switching among, episodes, according to individual student status. Different combinations and sequences of learning episodes can produce various learning flows that realize diverse instructional objectives relative to particular students' needs. Figure 1 depicts the three learning activity levels.

The WiTEC system supports many learning functions, facilitates various learning episodes, and allows for the development of multiple learning flows. It also increases the efficiency and convenience of classroom activities. Using WiTEC, the teacher can select learning functions to compose specific learning episodes and organize these episodes to create a learning flow that is suited to a particular learning objective or instructional strategy. Some of the learning functions supported in the WiTEC system are listed and analyzed below. Although this list of functions is not exhaustive, it presents a rough picture of the main elements of classroom activity supported by the system.

Content Presentation and Annotation

Whether a teacher is lecturing or students are presenting, they need a platform on which to display, explain, and, in the best of worlds, annotate content. Traditionally, teachers and students use a blackboard, a slide projector, or a wall chart to do this. In the WiTEC system, teachers and students can present content using a

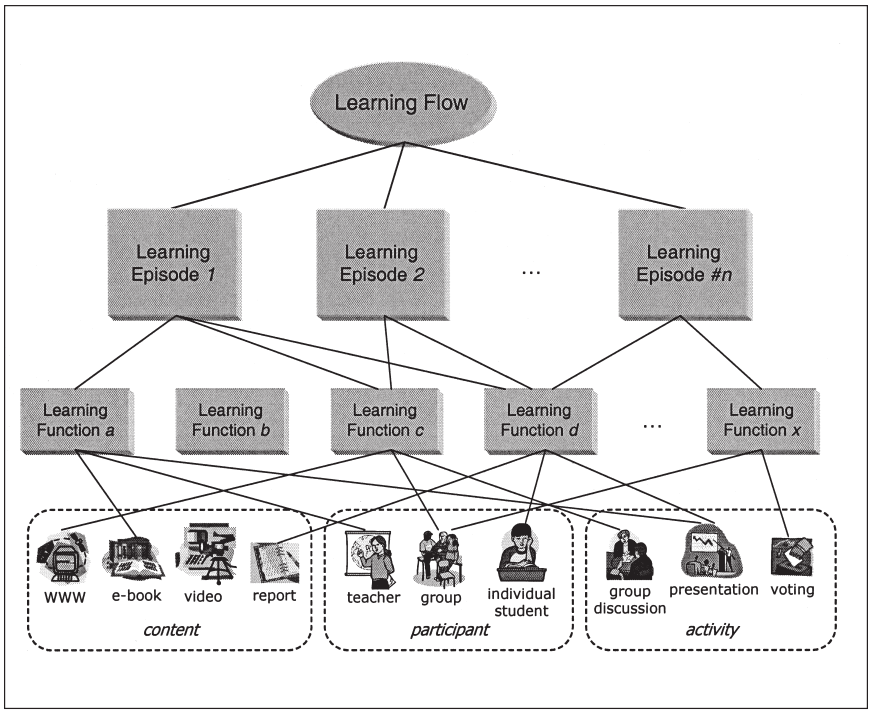

Figure 1. Three learning activity levels.

variety of media devices including a video projector, and these can be operated and the content annotated using an electronic whiteboard.

Content Transmission and Replaying Annotations

Although students can buy textbooks, keep track of teachers' hand-outs, and download files from networks before or after class, when the teacher is lecturing they are usually busy taking notes. In WiTEC, the teacher can transmit content and annotations to students' MLDs immediately, so students do not have to take notes, allowing them to concentrate on the teacher's lecture. The students can review the content on their MLDs and even replay the teacher's annotations after class. Students can also make and save their own annotations.

Student Mapping and Control

Understanding the progress of students during activities can help a teacher to manage a class. Using the WiTEC system, the teacher can observe an individual student's status unobtrusively or control his or her MLD, such as disabling some

functions or locking the screen of the MLD to ensure that the students focus on the current activity.

Work Construction and Co-Construction

In traditional classrooms, when students do or collaborate on work, they may use pencil and paper, the blackboard, or other devices. MLDs enable students to search for relevant information from the WWW, present their thoughts, and work with certain software packages, all on the same device. Furthermore, each student can work on his/her MLD and then transmit the work to other students' MLDs to exchange ideas and merge work into a group project.

Voting and Quiz

During an activity, the teacher may take a vote or administer a quiz to elicit students' responses or assess their understanding. Traditionally, teachers ask students to raise their hands to answer questions or to write an evaluation. In the WiTEC system, the teacher can display questions on an electronic whiteboard and the students can use their MLD to vote or answer questions. The students' answers are sent to a server and statistical results are immediately calculated and displayed on the whiteboard. Anonymous votes can also be taken.

By adopting the framework of three levels of learning activity in WiTEC, system developers can freely add new learning functions to the system to meet practical needs and extend the applications of the system in the classroom. Well-arranged learning episodes can be used to implement specific instructional strategies which can be shared with other teachers. Moreover, learning flows allow a teacher to think about instructional procedures before class, guide both instruction and learning in class, and review students' learning portfolios after class.

SYSTEM DESCRIPTION

WiTEC provides students and teachers with the advantages of ubiquitous computing within an integrated system. The integrated system includes an instructional support subsystem for teachers, a learning support subsystem for students, and a collaboration mechanism supported by learning functions. It provides tools for supporting not only in-class instruction and learning, but also preparation before class and review after class.

Instructional Support Subsystem

In the WiTEC system, the instructional support subsystem combines an interactive instruction center with a resource and class management server to support teachers in preparing, implementing, and reviewing instruction. The teacher uses

the interactive instruction center to control the pace of instruction, to monitor student status and to conduct activities. Table 1 lists the learning functions of each subsystem; ISS is the abbreviation for Instructional Support Subsystem and LSS is the abbreviation for Learning Support Subsystem. Every learning function associates action, content, and participants. The "voting" function, for example, enables an entire class of students (participants) to vote (action) on a question (content). The teacher can set up the type of question and the number of allowed responses. A graphical representation of responses can be instantly generated and displayed in the interactive instruction center.

The functions of the instructional support subsystem support both teacher-oriented and student-oriented activities. For example, "annotation" and "content delivery" are teacher-oriented functions which support a teacher in lecturing to an entire class. Student-oriented activities include "co-construction of report" and "quiz." Group members are automatically logged into the resource and class management server to edit their group reports. They can discuss details face-to-face, modify the content of pages, change the order of the pages, and insert and/or delete pages.

A learning flow editing tool in the instructional support subsystem enables teachers to arrange the learning flow before class. Figure 2 presents a screen shot of the editing of a learning flow. A teacher generates a learning flow by simply labeling it and adding learning episodes into it. A learning episode is similarly generated by naming it and selecting learning functions from the list of functions. Each learning function automatically incorporates related materials, so the teacher does not need to choose this content explicitly. Additionally, the teacher can implement an available learning flow at any time.

For example, the teacher can generate a learning flow, named "collaborative project-based learning," which includes six learning episodes: "introductory discussion," "group discussion and information gathering," "co-constructing group product," "group presentations," "peer-evaluations among groups," and "discussion and conclusion." The "introductory discussion" episode might include two learning functions, "annotation" and "content delivery." The "co-constructing group product" episode might include two learning functions, "co-construction of report" and "co-construction of quiz."

Figure 3 shows a screen shot illustrating the construction of the learning episode "introductory discussion." The teacher first clicks the learning function labeled "annotation" in the learning flow area and the associated e-book file is automatically displayed in the content area of the frame. The teacher can now use annotation tools to annotate the e-book. After the teacher has completed the annotations, he or she clicks the learning function labeled "content delivery" and the current display of e-book, including the annotations, is transmitted to the MLDs of the entire class. The learning flow is listed on the right hand side of the frame. When the teacher clicks on one of the episodes in the learning flow, the list of functions associated with the episode will be extended as a menu. The

Table 1. Learning Functions of the Integrated System

Function	Action	Content	Participants	Subsystem	
				ISS	LSS
Annotation	Annotations on e-book	e-book	Teacher	3	
	Annotations on e-book	e-book	Individual student		3
Content delivery	Transmit content to student	e-book, URL link, presentation file, image	Individual student, group, or whole class	3	
	Receive content from teacher	e-book, URL link, presentation file, image	Individual student		3
Co-construction of quiz	Compose items to form a quiz	Quiz file	Group member	3	
	Edit items of a quiz	Quiz file	Group member		3
Co-construction of report	Compose pages to form a group report	Report file	Group member	3	
	Edit pages of a report	Report file	Group member		3
Quiz	Whole class based simultaneous test	Quiz file	Whole class	3	
	Respond to items of a quiz	Quiz file	Individual student		3

Voting	Collect individual response and display statistical results	Question	Whole class	3	
	Respond to question and transmit the response to the teacher	Question	Individual student		3
Group work presentation	Retrieve and display presentation file	Presentation file	Group member	3	
Replay annotations	Replay annotations	Annotations	Teacher	3	
Replay learning records	Replay individual student's annotations	Learning records	Individual student	3	
Student mapping and control	Display students' statuses/retrieve individual student's learning records	Statuses of interactive learning centers/ Individual student's learning records	Whole class/ individual student	3	
Notebook	Free sketch on notebook	Sketches	Individual student		3

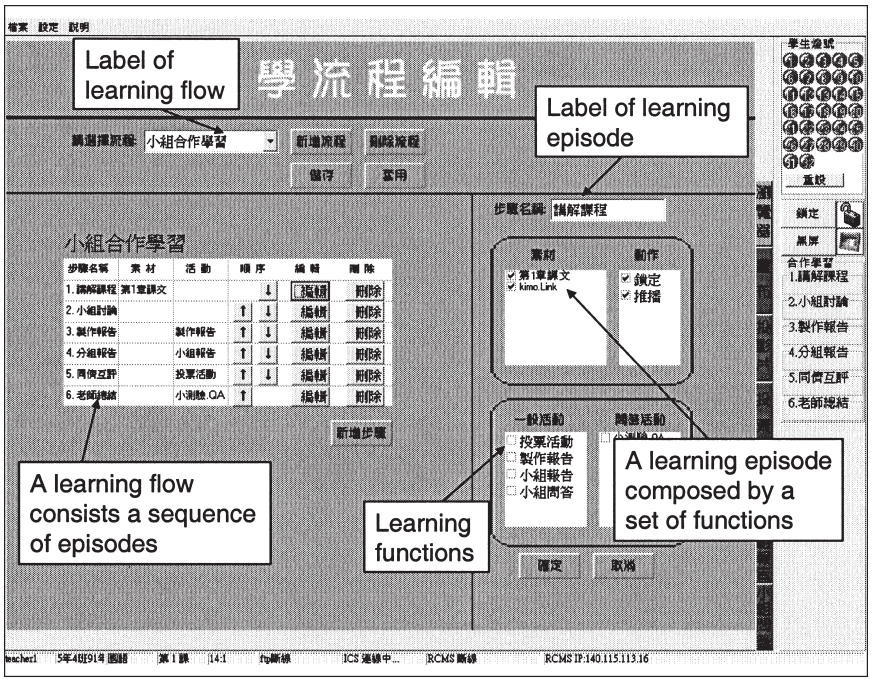

Figure 2. The teacher uses the learning flow editing tool to arrange activities before class.

status of all students' MLDs are displayed in the upper right corner, enabling the teacher to continuously monitor the progress of his or her students as they perform an activity. This area is also the interface for retrieving individual student's learning records.

WiTEC, which adopts client-server architecture, provides the flexibility to add, delete, and organize learning functions for instruction. Before class, the teacher arranges the learning flow in the interactive instruction center, and the flow is stored in the resource and class management server. In class, the teacher retrieves the learning flow from the resource and class management server and runs each learning function in the interactive instruction center. After class, the teacher and students can retrieve instruction and learning records from the resource and class management server.

Learning Support Subsystem

Table 1 lists several functions in the learning support subsystem for students which correspond to functions in the instructional support subsystem. For example,

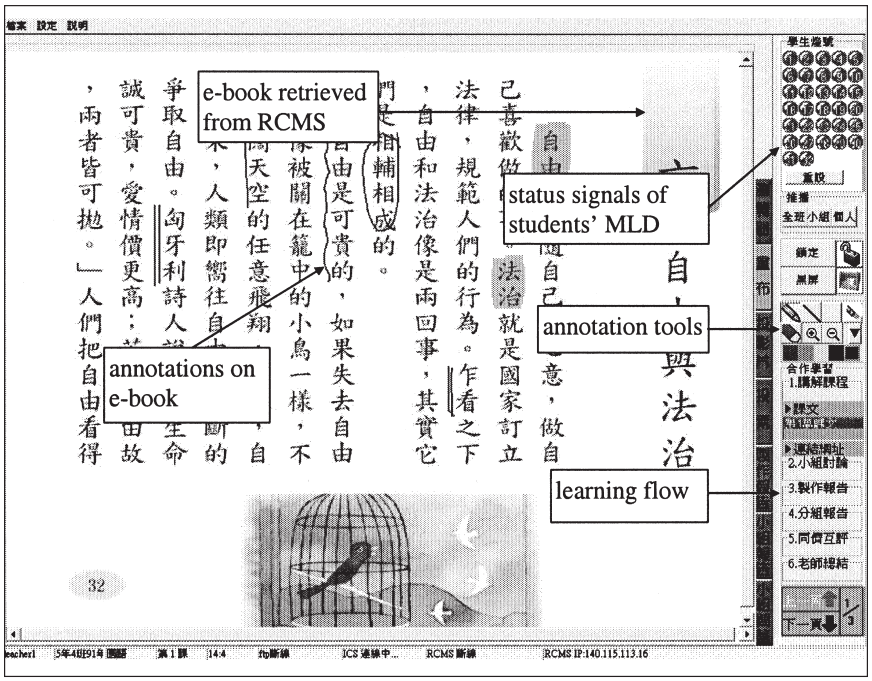

Figure 3. A snapshot of the implementation of the learning function, "annotation."

once the teacher performs the instructional function "voting," every student's interactive learning center automatically activates the corresponding "voting" function. A number pad pops up on the screen of each student's MLD and waits for a response. After the student clicks one of the number buttons, the response is sent to the interactive instruction center and graphical results are instantly shown in the interactive instruction center (whiteboard). Besides the functions that correspond to those of the instructional support subsystem, the learning support subsystem also includes isolated execution functions, such as "notebook" and "annotation."

The learning support subsystem combines an interactive learning center with a resource and class management server. The resource and class management server stores learning materials, student profiles, and group settings. Once an MLD is booted up, it is automatically logged into the resource and class management server as one of the group to which it belongs. The MLD's memory only stores temporary data. After a learning function is implemented, the content temporarily stored in the MLD is transferred to the appropriate area of the resource and class management server. Group-created products are stored in the group area of

the resource and class management server. Figure 4 shows the screen after the learning function "quiz" has been completed: the statistical results are stored in the resource and class management server and graphically displayed in the interactive learning center.

Collaboration Mechanism

Most collaborative learning activities require learners to create relevant materials and make them accessible to others (Ferraris, Brunier, & Martel, 2002). Such collaborative activities allow students to share each other's writing, pictures, notes and other constructed materials, sometimes via a Web-based interface (Hoppe et al., 2000). Pupils are loosely coupled during learning. However, there still are many kinds of learning activities, especially simultaneous group-based activities, which cannot be implemented in this manner.

Besides collaborative learning itself, many other activities also use collaborative mechanisms. The collaborative mechanism supported by learning functions is based on the resource and class management server and the interactive classroom server. The resource and class management server is basically a Web-based collaborative activity center which provides peer groups with a shared working

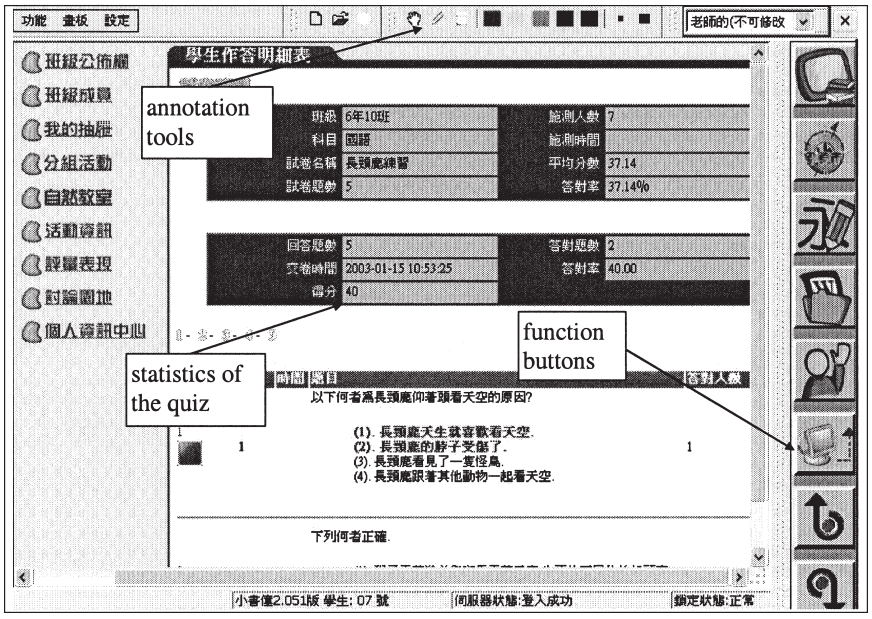

Figure 4. Statistical results after the interactive learning center has completed the learning function "quiz."

area while they are co-constructing group products. Additionally, the interactive classroom server coordinates not only the actions but also the content of learning functions. For example, a teacher can transmit a project guideline to a designated group by implementing the "content transmission" function. The interactive instruction center first retrieves group setting information from the resource and class management server and then transmits the guideline to all members of the group via the interactive classroom server. Accordingly, the interactive classroom server is a synchronous collaborative activity coordinator that supports activities that must be processed or responded to in real-time.

Figure 5 illustrates the mechanism that coordinates activities between the interactive instruction center, the interactive learning center, and the interactive classroom server. The interactive classroom server consists of three blocks containing a total of seven modules. The daemon block is comprised of the daemon and protocol-parsing module. It receives, transmits, and parses highly interactive protocols. The connection management block includes the connection management and authentication modules. It authenticates logins from the

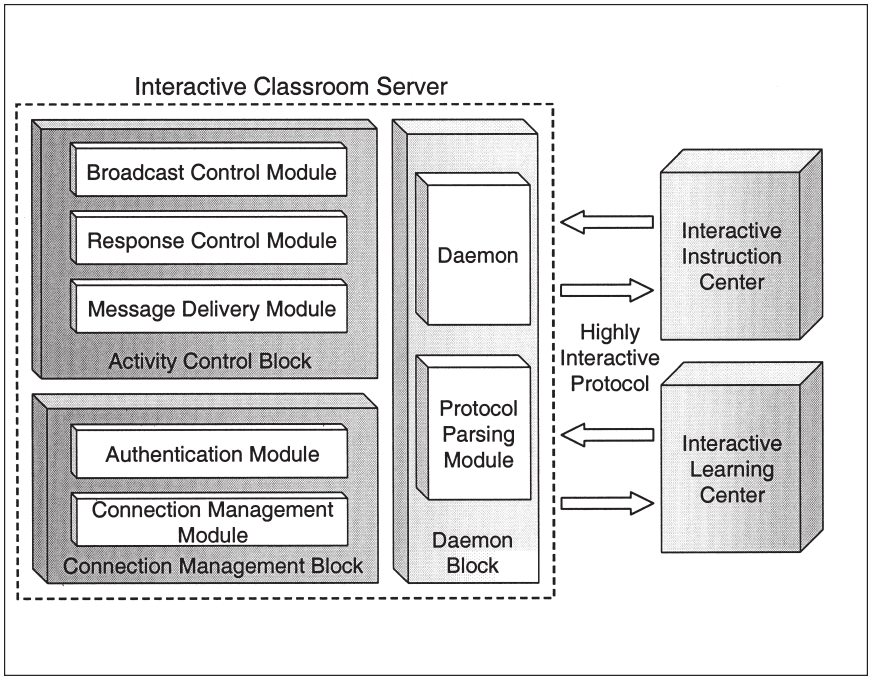

Figure 5. Seven modules in the interactive classroom server that support collaboration in WiTEC.

interactive learning center and the interactive instruction center; handles the connection of all interactive learning centers in the classroom using wireless communication; detects the connection status of each interactive learning center; and recovers disconnected ones. The activity control block consists of the message delivery, the response control, and the broadcast control modules. It processes both synchronous and asynchronous activity protocols. All of the synchronous activity protocols are processed by the broadcast control module and response control module, while asynchronous activity protocols are processed by the message delivery module.

For example, once the interactive instruction center has performed the "voting" function, it sends the corresponding highly interactive protocol to the daemon of the interactive classroom server. The protocol-parsing module parses the received protocol and passes it to the response control module. After the protocol is processed, the response is generated and sent to all interactive learning centers through the daemon to activate the "voting" function of the interactive learning center. In the interactive learning center, the activated "voting" function waits for each student's response. These responses are encapsulated and sent back to the interactive classroom server via the daemon to be parsed by the protocol parsing module. The response control module then sends the response to the interactive instruction center. The final result of the "voting" function is displayed in the interactive instruction center.

The interactive classroom server also coordinates asynchronous activities. Once an interactive learning center has been activated for an asynchronous activity, such as "co-construction of report," it communicates with the interactive classroom server, is authenticated, and is automatically logged into the area of the resource and class management server that belongs to its group. Subsequent operations are directly processed between the interactive learning center and the resource and class management server, without coordination through the interactive classroom server.

EVALUATION

A two-stage evaluation of the usability of the integrated system and the feasibility of the learning flow was conducted. The first stage of the evaluation involved the initial version of the WiTEC system before learning flow operations were implemented. It focused on teachers' perceptions of the usefulness of the learning and instructional functions implemented in the WiTEC system. The second stage of the evaluation assessed the efficacy of the WiTEC system with learning flow capacities implemented. It focused on the teachers' perceptions of the applicability of using the learning flow to organize class activities and whether and how the use of the WiTEC system can affect teaching and learning.

The subjects of both evaluations were the three teachers in Nan-Hu Elementary School, Taipei, Taiwan who participated in this experimental project. In these

classes, each student used a MLD equipped with a webpad, a 10.4 inch TFT-LCD, and a touch panel running Windows CE Traditional Chinese version OS and the learning support subsystem. The teachers used PCs running Windows 98 Traditional Chinese OS as well as the instructional support subsystem connected to a 72 inch electronic whiteboard.

Stage One Evaluation

From May 2002 to January 2003, the three participating classes used the first version of the integrated system. In this version, the learning flow was not developed and only some learning functions were available. The three participating teachers were interviewed in January 2003. The results of the interviews with the three teachers are summarized thematically in the following sections.

Complexity of WiTEC

The teachers found the WiTEC system interface to be user-friendly. They stated that they only needed two or three hours to become familiar with the operation of the entire system. However, it was noted that less frequently used functions still needed to be reviewed before formal usage—not because the functions were not clearly described, but because the large number and complexity of the functions made their specific operation difficult to remember.

Frequently Used Functions

The most frequently used function was "content transmission and annotation." Teachers stated these functions helped them to quickly present and broadcast pre-prepared digital materials to the students. They noted that when they had previously used text materials in class, many students had trouble finding materials and keeping up with them. This rarely happened when they used the content transmission and annotation function. Another function the teachers reported using often was the "voting" function. This function enabled their students to respond anonymously and to see results immediately. The teachers also reported using the "co-construction of report" function. One stated, "If I am planning to ask the students to conduct a group discussion and write a report, I will arrange the assignment and questions before class, and broadcast them to each group during the class."

Favorite Functions

When asked what their favorite functions in the WiTEC system were, teachers identified the "replay learning records" function because it "is useful for sharing learning results with the whole class and it allows me to see students' learning status immediately"; and the "co-construction of report" function because "in-group members can use this function to co-create, share, or revise group

reports." One teacher stated, "I select the function that is appropriate to the current part of the course and have no specific preference."

Functions That Should Be Added

Teachers stated that they found the functions of the WiTEC system plentiful and useful, so plentiful in fact that they were sometimes burdened by having to consider next steps and which functions to use. Thus, they suggested adding some functions to facilitate the application of these. They also suggested including a calculator and/or a space for calculations.

In summary, the teachers had positive attitudes toward the WiTEC system, but saw room for improvement in its usability and convenience. All of the teachers felt that many functions of the integrated system were very useful, but they also thought that some of the functions of the system increased the burden of using it.

Stage Two Evaluation

From January 2003 to May 2003, the three participating classes adopted the second version of the integrated WiTEC system, which included basic functions similar to those of the first version, but with the addition of the learning flow functionality. The teachers first applied the learning flow system in four-week collaborative learning projects. They were then interviewed, and the interview results were analyzed. In the sections which follow, we first describe the three-phase implementation of the collaborative learning projects. We then report the interview findings and discuss the evaluation results.

Applying Learning Flow to Collaborative Learning

Preparation Phase—To prepare for the collaborative learning projects, the teachers used the students' score management function to access the baseline scores of each of their students, and then divided students into heterogeneous groups according to their past learning performances. The teachers then used the functions of the resource and class management server to design different learning projects for every group and to link these to relevant resources.

Execution Phase (Implementing Learning Flow)—At the beginning of the collaborative unit, the teachers introduced project-based learning and the specific unit, and broadcast relevant resources and guidance to individual students and groups through the interactive learning center. The group members discussed their assigned projects face-to-face and searched for additional resources online as necessary. Through exploration, discussion, communication, debate, clarification, and collaboration, group members worked on their projects and built individual learning portfolios on their personal MLDs. According to the division of labor, group members completed their individual components of the group work, then exchanged and combined individual reports to complete the group project.

Each group selected one or several representatives to present their group report on the electronic whiteboard. Some groups designed items in advance, broadcast them to other groups for further interaction, and saved these in the resource and class management server. As each group presented its project, the members of other groups evaluated them using the synchronous group interaction function. The teachers displayed these results to the whole class on the electronic whiteboard. The peer assessments were saved in the resource and class management server together with the learning portfolios for each group and individuals within each group. In addition, while each group project was displayed on the electronic whiteboard, the teachers conducted discussions with their classes, summarizing group findings and reflecting on their results in the context of project-based learning.

Follow-Up Phase (Using the Products of the Learning Flow)—Following group presentations, the WiTEC system calculated improvements in individual performance and group achievement based on peer, self, and teacher assessments. It also saved various comments on the projects with the projects themselves. Each group revised its project accordingly, based on these stored suggestions. After the projects were revised, the groups saved their final projects in the resource and class management server for further reference. The teachers used this resource to retrieve the group projects and each student's learning portfolio and assign them grades.

Interview Findings

Preparation Phase—Teachers reported that the learning flow mechanism enabled them to use WiTEC more structurally and systematically. They found that they could simply identify instructional objectives and activities step by step to create their instructional materials in correspondence to the system functions. Two of the three teachers stated that they felt that the learning flow enabled them to follow easy and clear procedures to prepare instructional activities. The teachers also noted that when they mapped the learning flow, they were also clarifying the steps and content involved in an instructional activity. One teacher, for example, stated that "using the learning flow to draw up instructional materials and activities helps teachers to think over the instruction process."

Execution Phase—In using the learning flow in class, the digital instructional materials and system functions required by every instructional procedure can be shown in order, so the learning flow can guide the teacher's instruction. The teachers particularly liked this characteristic of the system. For example, one teacher stated, "Sometimes I forget what to do for the next step during class. When I use this system, I know exactly what the next instruction activity is." Another remarked, "When I employ unfamiliar instructional procedures, I usually preview the lesson by myself but then inevitably forget something during class. The system

helps me to know where we are, and helps the students to know what they must do next."

When teachers apply the learning flow to in-class instruction, what they need to do is simply click on certain procedures at the proper time. The teachers felt that this process both saved them time and reduced their cognitive load while presenting the materials and conducting their classes. One teacher, for example, stated, "When I use information technology to teach, I worry I will not remember when to use a particular function or that I will forget to present some materials. Pre-editing the instructional procedures prevents me from going through the class in a disorderly way, so I save time and can concentrate on the students' learning."

Follow-Up Phase—Even though the first version of the system kept track of students' learning processes, it was often difficult to access these because there were too many portfolios. Using the new version of the system, teachers could organize and sort the students' learning portfolios according to the sequence of the learning flow. The teachers found this feature very helpful for clearly reviewing the contexts of the portfolios. One teacher, for example, noted, "Reviewing and evaluating students' in-class work according to the sequence of the learning flow enabled me to review the students' in-class work while thinking about the instructional context in which they were completed. This allowed me, on the one hand, to evaluate the students' works more deeply, and on the other hand, to reflect on my instruction." Another teacher stated, "When I used information technology in the past, students' portfolios were often dispersed in different files and so reviewing and correcting them required much time. The learning flow enabled me to review the entire instructional sequence in order. If a student's portfolio required correcting, I could go to the editing part to do some correction immediately."

In addition to making teaching with technology easier in the first place, the teachers also noted that the learning flow system made it easier to build lessons and units year to year. For example, one teacher remarked, "When using information technology in the past, I found that managing portfolios was not easy. When I repeated a class in the following year, I didn't know where the portfolios were or what the entire process was. Using the learning flow solved this problem."

SUMMARY OF THE EVALUATION FINDINGS

The evaluation results reveal that before learning flow was applied the three participating teachers regarded the various functions in the WiTEC as helpful in teaching, but found that the large number and complexity of the system's functions increased their burden during teaching. After the learning flow mechanisms were introduced, the teachers reported that these enabled them easily to design WiTEC-based instructional activities before class. This process also helped them to think in advance about the instructional procedures they would use. During

instruction, the learning flow not only guided both teachers and students, but also saved time and reduced the teachers' cognitive load. After the instructional activities ended, the learning flow provided a context through which the teachers could review the students' learning portfolios, facilitating the teachers' revision of some instructional procedures and resources. In summary, the introduction of learning flow mechanisms solved the earlier problems associated with the WiTEC system, allowing teachers to use the various functions of the WiTEC anytime during instruction with less effort, and had the added benefit of improving teachers' construction of and reflection on their instructional practice.

SUMMARY AND CONCLUSION

This article presents a framework that incorporates three learning activity levels—learning function, learning episode, and learning flow—to provide an effective and efficient method for arranging learning and coordinating activities in ubiquitous computing classrooms supported by the WiTEC system. Learning flow is a series of learning episodes that are composed of learning functions. The learning episode is the basic unit of a learning activity. Learning functions can be added as required to form new learning episodes. When a teacher wants to perform a specific learning activity, s/he can create appropriate learning episodes from basic functions to form and then implement the needed learning flow. In addition, a system developer can add new learning functions to the system to support teachers and students in new forms of instruction and learning. Teachers can exchange their learning activity designs in the form of a learning episodes. Within the learning flow framework, the WiTEC system integrates three separate subsystems—an instructional support subsystem for teachers, a learning support subsystem for students, and a collaboration mechanism supported by learning functions.

The original WiTEC system and the integrated (learning flow) WiTEC systems were installed in three elementary classrooms in Taipei City to conduct a two-stage evaluation which included a formative revision. Interviews with the three participated teachers revealed that they felt that the learning flow mechanism made them think in advance about instructional procedures and ensure that they were comprehensive. Using the learning flow in class not only guided both learning and instruction, but also saved time and reduced cognitive load. Moreover, the learning flow mechanisms helped teachers to integrate students' learning processes with the instructional activities, and helped them to revise activities after class for future use. In summary, the framework of three learning activity levels enhanced the usability and feasibility of the WiTEC system. However, the two-stage evaluation focused on the application of the integrated WiTEC system to project-based collaborative learning. It should be further tested for other kinds of instruction and learning models.

The framework of the three learning activity levels in a ubiquitous computing learning environment can be improved in many ways: 1) by developing more learning functions to support a wide range of teaching and learning practices, including indoor and outdoor learning, collaborative/individual learning, and others; 2) by creating a mechanism for exchanging learning episodes to help teachers share their knowledge about designing learning activities; and 3) by providing templates for learning flow, to reduce the time required to prepare courses.

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