Teaching in a wireless learning environment: A case study

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ABSTRACT

Although wireless and mobile technology is regarded as a useful tool for enhancing student-centered learning, few studies have explored the factors that may affect the application of this emerging technology in classroom situations. Accordingly, this study selects three factors (instructional belief, instructional routine, and features of wireless and mobile technology) via literature review, then utilizes a case-study method with a focus class and teacher to explore the effects of these factors on teaching in wireless environments. The main study results are summarized as follows: first, the case teacher held positive beliefs regarding student-centered instruction and innovative technology, but the teacher's instructional practices were significantly restricted by the teacher-centered approach. This inconsistency between instructional beliefs and practices resulted in the teacher being willing to apply wireless technology but unable to bring it into full play. Second, the strong stress and misgivings about changes in instructional methods prevented the teacher from altering instructional routines. The contrast between student expectations regarding technological applications and the practical application of technology by teachers caused negative reciprocal effects. Finally, the workshop that adopted top-down dissemination and did not use on-site support in this study cannot encourage changes in instruction methods used by teachers. It is recommended that effective learning communities and teacher development programs be developed.

Keywords

Instructional change, Technology and instruction, Wireless & mobile technology, Teacher belief, Innovative educational technology

Introduction

Technology is often considered valuable for increasing educational benefits and instructional quality (Dexter, Anderson, & Becker, 1999). Mobile devices, wireless communications, and network technology have recently advanced significantly, and have been integrated into various wireless learning environments that attract many individuals' attention and expectations (Roschelle & Pea, 2002; Norris & Soloway, 2004). For instance, many studies have predicted that wireless learning environments have the potential to create something new and significantly impact education (Roblyer, 2003; Roschelle, 2003; Penuel, Tatar, & Roschelle, 2004).

Wireless learning environments offer many educational possibilities that are not easily achieved in other learning environments. Mobile devices enable both the teacher and students to employ computing power without time or location constraints, while the Internet and wireless technologies enable mobile devices to interconnect seamlessly with each other or with other computing devices. Wireless learning environments have the following features based on seamlessly linking various computing powers with mobile learning devices at hand, including: (1) enhancing availability and accessibility of information networks; (2) engaging students in learning-related activities in diverse physical locations; (3) supporting group work in projects; (4) improving communication and collaborative learning in the classroom, and (5) supporting quick content delivery (Gay, Stefanone, Grace-Martin, & Hembrooke, 2001; Roschelle & Pea, 2002; Hoppe, Joiner, Milrad, & Sharples, 2003; Liu et al., 2003; Wang, Liu**,** Chou, Liang, & Chan, 2004; Liang et al., 2005; Zurita, Nussbaum, & Salinas, 2005). Therefore, wireless learning environments are regarded as more suitable than ordinary classrooms or computer classrooms for supporting teaching and learning based on learner-centered teaching methods (Roschelle, 2003; Zurita et al., 2005), described as "active, productive, creative and collaborative learning methods" (p. 255) by Hoppe et al. (2003).

Although previous survey studies demonstrated that wireless learning environments can increase students' application time of IT and improve their learning achievement and attitude (Crawford & Vahey, 2002; Swan, van't Hooft, Kratcoski, & Unger, 2005), some researchers (van't Hooft & Swan, 2004) have pointed out the insufficient number of empirical studies on the educational applications of wireless and mobile technologies. Learning with innovative technologies does not automatically provide the benefits of these technologies. Many factors influence the application of technology in classrooms and determine its educational benefits, such as the pedagogical approach of

teachers, technology used, infrastructure and support, training regarding technology application, teacher attitudes about educational technology, teacher classroom practices, classroom management skills, and so on (Greenberg, Raphael, Keller, & Tobias, 1998; Zucker, 2004). Because the factors affecting technology application affect each other, the actual influences and effect processes of these factors are difficult to identify.

Moreover, most researchers and teachers do not understand emerging wireless learning environments as well as they do ordinary classrooms and computer classrooms. The factors affecting teaching and learning in wireless environments and their effects are not yet clear and, therefore, must be intensively explored before strongly promoting teaching in wireless learning environments (Penuel et al., 2004; Zucker, 2004; Zurita & Nussbaum, 2004).

A case study is a particularly appropriate way to explore the possible effects on teaching and learning of wireless and mobile technologies. As an empirical and holistic inquiry, a case study explores a single instance, phenomenon, or social unit within its natural setting (Yin, 1994; Merriam, 1998). Case studies are often adopted to study the problems or effects that a specific case (a class with a teacher) encounters when it applies innovative technologies in a classroom (e.g. Lin, 2001; Seppala & Alamaki, 2003; Young, 2003), and can form the basis for the development of more general, nomothetic theories.

In this study, which is in the first in this series, a case study involving real classroom situations was conducted to explore the possible factors affecting teaching and learning by wireless technology with the following purposes: (1) to identify how these factors affect teaching and learning in wireless learning environments; (2) to understand how these factors affect teaching and learning; (3) to discover how these factors may mutually affect each other, and (4) to recommend directions for the teacher and students in current case study as well as in future studies and training programs that incorporate wireless learning environments into classrooms.

The factors explored in this study

Theories or related research results can be adopted as the starting points to direct or construct the initial set of research questions, and then to explore the case study (Yin, 1994). Some earlier studies found that many interdependent factors influence teaching and learning in wireless learning environments (Zucker, 2004). However, focusing on too many possible factors in one study may make the work too complex to control. Hence, this study initially chose three major factors: the teacher's instructional beliefs, the teacher's instructional routine, and the wireless learning environment. The definitions of these factors, the relevant literature, and the reasons for choosing them are presented below.

Teacher's instructional beliefs

Teachers' instructional beliefs, which reflect their own implicit theories and assumptions about the students, the subjects they teach, the teaching approach, and their teaching responsibilities, are often considered to play an essential role in their classroom practice (Higgins & Moseley, 2001). Some literature has stated that teachers' instructional beliefs directly influence their pedagogical practices and interaction with students (Clark & Yinger, 1987), and also affect students' learning achievements (Thompson, 1984; Ernest, 1989; Lerman, 1989; Fennema & Franke, 1992).

However, various studies disagree about whether teachers' instructional beliefs are consistent with their own instructional practices (Fang, 1996). For example, some studies have indicated that teachers' instructional beliefs are linked to their pedagogical practices (e.g. Johnson, 1992) or their educational applications of information technology (Drenoyianni & Selwood, 1998; Higgins & Moseley, 2001), while others have concluded that teachers' instructional practices do not always conform to their beliefs (Duffy & Anderson, 1984; Thompson, 1992; Raymond, 1997; Wilson & Goldenberg, 1998).

Because the earlier investigations lacked unanimous results, and because wireless learning environments have the potential to support learner-centered activities, the current study tries to further explore the possible relationships between teachers' instructional beliefs (teacher-centered or learner-centered approaches) and their own instructional practice with wireless technology, and the possible reasons for those relationships.

Teacher's instructional routines

Instructional routines based on teachers' previous teaching experiences are efficient and common instructional modes in situations involving repetitive actions and behavior (Yinger, 1979). Some studies have indicated the practical teaching of teachers frequently follows their own instructional routines (e.g. Parker & Gehrke, 1986). Instructional routines, when applied properly, can increase the teachers' effectiveness by freeing their time and energies from decision-making during instruction (Yinger, 1979). However, the features of instructional routines, intuition and automation may also reduce the flexibility and changeability of teacher instructional practices when teachers implement innovative technologies, such as wireless and mobile technologies.

The introduction of innovative technologies into the classroom increases the complexity and unpredictability of instructional and learning situations (Fang, 1996), and often requires teachers to adjust their usual practices of instructional decision according to the novel situations. However, when trying to implement innovated technologies, teachers often resist changing their instruction, reducing the flexibility of their instructional decisions, and preventing the technology implementation from producing the expected educational benefits (Drenoyianni & Selwood, 1998).

Based on the above literature, this work studied how teachers' instructional routines affect their own practical teaching and technology application in the wireless learning environment.

The wireless learning environment

Mobile and wireless technologies have become very promising technologies for supporting learner-centered learning (Hoppe et al., 2003). Their integration can expand technologies as part of the campus environment for teachers and students to adopt and enable students to share information and coordinate their works (Gay et al., 2001).

The educational application of mobile and wireless technology rises rapidly, but empirical studies on learning activities involving these technologies are still rare. Most empirical studies adopted the interview or questionnaire method to evaluate the effectiveness of wireless learning environment. The following conclusions were drawn: **(1) Improving learning achievements.** Some studies have revealed that wireless mobile devices improve student learning across curricular topics and instructional activities (Crawford & Vahey, 2002). Moreover, the application of mobile learning devices has been found to enhance students' learning processes, support students' completing schoolwork, and improve students' conceptual understanding (Swan et al., 2005). **(2) Promoting learning motivations.** Swan et al. (2005) found that mobile computing devices excite students and engage them in learning, especially when they are writing by hand. Teachers have found that students are more motivated and spend more time learning when they use mobile learning devices (Crawford & Vahey, 2002)., than they do in the traditional classroom. Van't Hooft, Diaz, & Swan (2004) performed a survey of 217 students and found that most students liked using mobile devices, thought using mobile devices made learning more fun, and viewed mobile devices as a valuable learning tool.

Although the results of the above study could popularize efforts to teach in wireless learning environments, many details are worth further study. For instance, some empirical studies (van't Hooft et al., 2004) found that most students often adopt mobile devices for activities unrelated to formal learning (such as playing games). Accordingly, some questions emerge regarding whether teachers agree that students use their own mobile learning devices freely and flexibly in classrooms and whether students will still have positive attitudes to learning within wireless learning environments if teachers restrict the way students use their own devices. To explore these questions, this study collects and analyzes data about student learning attitudes.

Central Questions

The following four sets of central questions for the study have been identified from the research literature.

- How are the case teacher's practical instructions (in an ordinary classroom or the wireless learning environment) and his/her own beliefs about instructions and technology applications related? Additionally, why do these relationships occur?

- How and why do the teacher's instructional routines affect his/her own practical teaching and technology application in the wireless learning environment?
- How does the wireless learning environment support the teacher in implementing appropriate instructional practices and technology applications?
- What are the mutual effects among these factors (such as beliefs about instruction and technology application, instructional routine, and wireless instructional environment) during teaching and learning in wireless learning environments? Additionally, how do these effects further influence student attitudes toward learning with wireless technology?

Research Design and Method

To study deeply the effects of various factors on teaching and learning in the wireless environment through detailed and intensive classroom observation in real situations, this study performed a case-study approach, and employed a focus class to collect and analyze data about learning mathematics in wireless learning environments.

Case selection

Before the current study was conducted, several elementary schools had been selected as the key schools of IT, and given financial assistance by the government of Taipei City, Taiwan to set up wireless learning environments. The purposeful selection was employed to select the study case from among the teachers and their classes of these schools, and the major selection criteria are displayed as follows: (1) the school administrators must support the case study, and the case class must permit long-term observation in the classroom to collect data about teaching and learning in real situations; (2) the class in the case study must be in the fifth or sixth because students in these grades can already utilize and implement learning devices; (3) the class teacher must have enough teaching experience to form his or her own instructional routines, and (4) the teacher and students in the class must be unfamiliar with the applications of innovative technologies.

The target teachers were individually interviewed to inform them of the purposes and procedures of this study, and to ascertain their willingness to participate in this study. Finally, a teacher and class that met the selection criteria were chosen for the study. Furthermore, the researchers were invited to report the purposes and procedures of this study to the students' parents. The students' parents then agreed to allow their children to participate in the study.

The school of the selected case teacher and class had a long history, and old buildings and instructional facilities. The principal of this school actively supported this study and expected that the current study could illustrate the problems confronting the case class.

The case teacher, who had more than ten years' teaching experience in this elementary school, had taught the case class for over a year before this study began. The teacher had basic IT skills, such as those require for the editing of digital briefings and word processing, and considered IT useful in education, but seldom applied IT technologies practically in his teaching. Moreover, the teacher was very active and enthusiastic about the teaching profession. His motives for participating in this study were to attempt to apply wireless technologies in education, and to review and improve his own teaching skills.

The selected class was made up of students in the sixth grade, several of whom had no computer in the home. The classroom contained a computer connected to a fixed overhead projector. The case teacher often used this computer to edit instructional materials and assignments, but rarely applied the projector in teaching.

The wireless learning environment applied in current study

The wireless learning environment of the case class was the Wireless Technology Enhanced Classroom (WiTEC), which was financially supported by the Taipei city government. The WiTEC system was developed in 2001 by the Learning Technology Center of National Central University, Taiwan. In the study, WiTEC was suitable as a wireless learning environment for two reasons. First, WiTEC, designed for general learning purposes, has features common to

many wireless learning environments, as described in the second paragraph of the introduction. Therefore, the results of this study can be generalized to many wireless learning environments. Second, the earlier studies discovered that the seven modules (see Table 1) of WiTEC can be flexibly and easily applied to support learner-centered activities, such as cooperative/collaborative learning activities (Wang, Liu**,** Chou, Liang, & Chan, 2004) and project-based learning activities (Liu, et al., 2003). Thus, WiTEC could help the current study in exploring whether the case teacher adapts the coincident instructional approach in the wireless learning environment.

Table 1. Seven modules and related functions of WiTEC

Modules	Major users	Functions
Displaying	Teacher	Illustrating prepared digital materials, and taking notes on the e-whiteboard
Broadcasting	Teacher	Transmitting information shown on the e-whiteboard, such as digital materials and notes, to all students' tablet PCs.
Selective and Spot Inspection	Teacher	Obtaining students' assignments from their tablet PCs, displaying them and taking notes on them via the e-whiteboard
Individual Learning	Students	Reading learning materials, taking personal notes and revising their work via tablet PCs
Online Learning	Students	Searching, accessing, and saving online resources or interacting with communities outside the school via wireless networks
Cooperative Working	Students	Co-editing a group report with other group members
Integrated-response displaying	Teacher & Students	Teacher: Showing a multiple-choice item on the e-whiteboard Students: Sending their answers via learning devices Teacher: Showing the correct answer, students' responses, or frequency chart of students' option on the e-whiteboard

Note: The teacher can use the "lock" and "black screen" options to prevent students from operating their own mobile learning devices during teaching.

Data Sources

Observations of the teaching and learning activities in the case class: Non-participant observation was adopted to collect data about the case teacher's instructional practices and students' learning activities in real situations. The researchers sat at the back of the classroom to avoid interfering with the case teacher's teaching, and recorded the class activities.

Interviews with the case teacher: (1) The teacher was interviewed at the beginning of this study to collect data about his background, and his beliefs on instruction and the application of IT to education. The interviews were semi-structured. The original interview questions are listed in Appendix A. (2) The teacher was interviewed twice each week of the study to discuss how he taught mathematics on that day. The entire interview process was tape-recorded with permission of the teacher.

The case teacher's instructional documents: The following documents were used to complement and explain the records of the classroom observation: (1) ordinary documents, such as teaching materials, assignments, and examination papers, and (2) documents needed by the researcher, such as lesson plans and instructional journals.

The students' learning journals: After each mathematics lesson, all students of the case class were asked to take ten minutes to record their views on either or both the learning activity or their mood. The study assistants then immediately gathered the completed learning journals. The case teacher knew that his students had been asked to write learning journals, but he never saw the journal contents. In order to ensure understanding, further interviews were conducted with the students whose learning journals revealed unclear or incomplete ideas.

Data arrangement and analysis: The personal identifiers of the case teacher and students in different data were removed during the data-coding procedure.

The case teacher's instructional practices (including instructional routines): Triangulation was adopted to analyze instructional practices of the case teacher. The typewritten protocols of classroom observation, teacher's interview notes, observation notes, and instructional documents related to the same instructional activity were compared (with conclusions made) to represent the instructional routines or practices of the case teacher.

In addition, the researcher further clarified and classified the case teacher's instructional routines or practices as either teacher-centered or student-centered, based on six indexes (please see the Table 2).

Table 2. Indexes for classifying the instructional approach

Approaches / Indexes	**Teacher-centered** ⟵	⟶ **Student-centered**
Teacher roles	A transmitter or director	A guide, facilitator, or assistant,
Teaching goals	Delivery of factual knowledge	Construction of knowledge
Instructional methods	Lectures, demonstrations, etc.	Project-based or inquiry-based learning
Learning autonomy	Few opportunities for students to initiate and control their own learning procedures	Many opportunities for students to initiate and control their own learning procedures
Learning methods	Individual work	Peer collaboration/cooperation
Interactions between the teacher and students	IRF (initiation/response/follow-up) structure with short responses	Dialogic patterns to enhance student thinking

These indexes were derived from various literatures (Jonassen & Land, 2000; Roblyer, 2003) to represent the differences between two instructional approaches (teacher-centered and student-centered). These six indexes respectively represent the features of teacher roles, teaching goals, instructional methods, learning autonomy, learning works and classroom interactions for the two instructional approaches. Similar indexes have been used to identify different approaches for integrating educational technology into teaching (Roblyer, 2003) or the features of learning environments supported by technology (Jonassen & Land, 2000).

Dexter, Anderson, and Becker (1999) noted that technology-using teachers range along a continuum of instructional approaches, from teacher-centered to student-centered. The researchers of the current study contrasted the features of case-teacher instructional routines and practices with the indexes listed in Table 2 to determine the features of the instructional approach used by the case teacher.

Case teacher technology applications. According to the video records of the actual teaching by the case teacher in WiTEC, the time that the case teacher utilized each major function module (the detail of each module, please see Table 1) was recorded and calculated.

Student attitudes towards learning with wireless technology. To understand student learning attitudes, the student learning journals were classified according to their contents: "with positive comments," "with negative comments," "with both positive and negative comments," "with no comments," and "non-delivery." Then the frequency distributions of learning journals were calculated for different time periods and compared. Moreover, the qualitative data of learning journals and interview protocols were further analyzed to explore the influences on student learning attitudes.

Duration of the study

The study was divided into three major phases: before the wireless technologies were incorporated in the case class (Phase one); the case class familiarizing itself with wireless technologies and related activities (Phase two), and after the wireless technologies were incorporated in the case class (Phase three).

Phase one (8 weeks). The case teacher was first interviewed to ascertain his beliefs. The learning activities of the case class were then observed and recorded on video (about twice a week, for two periods of 40 minutes each time). The case teacher was interviewed at least once a week to collect data regarding his ideas about his teaching.

Phase two (4 weeks). The case teacher participated in workshops (six workshops, each six hours in length, for a total of 36 hours). By observing the expert teachers' demonstrations and through practical training in the WiTEC, the participants learned (see Appendix B): (1) how to operate the functions, (2) how to implement collaborative-learning activities in the wireless learning environment, and (3) how to design applicable instructional materials. Appendix B shows the phases and main instructional tasks of the collaborative learning activities in the wireless learning environment that the expert teachers demonstrated, and the participants learned by practical training.

Furthermore, the case class students were guided to master the operations of their own mobile learning devices (six two-hour lessons, for a total of 12 hours).

Phase three (8 weeks). This phase aimed to clarify and analyze: (1) the case teacher's instructional practices and applications of technology in the wireless learning environment, and (2) the ideas and comments of both the case teacher and the students regarding learning and teaching with wireless technology. The case teacher's mathematics lessons continued to be observed and recorded twice a week, and the teacher was still interviewed to collect his views on his teaching at least once a week. However, unlike in Phase 1, the key aims of the observation and interview were to collect data not only about the case teacher's instructional practices but also about his application of technology.

Results

Phase one: Before wireless technology was introduced into the classroom

The interview data on the case teacher's beliefs indicate that he thought that the learner-centered approach was better than the teacher-centered approach, and that he expected himself to guide and encourage students' active learning. For instance, the case teacher responded to the researcher's question, "What role do you think the teacher should play during teaching?" by saying that, in the past, teachers were like dominators teaching in their own way in their classroom but now students are the protagonists and teachers should be the guides. Moreover, the case teacher stated that implanting knowledge was emphasized in the past, and now the heuristic or constructivist teaching method is seen as correct. Therefore, the case teacher expected himself to be a competent guide.

The interview results also reveal that the case teacher was willing to teach with wireless technologies, and that he thought that wireless technologies are effective teaching tools that can help students learn actively. For instance, the case teacher answered the question, "What does you think about wireless technologies?" by stating that he was willing to try to apply wireless technology because he thought that it could help his teaching, even though he had seldom applied IT in his class before. He also indicated that giving every student his or her own tablet PC could make learning more enjoyable.

Conversely, the analytical results on the case teacher's instructional practices indicate that the case teacher's teaching tended toward the teacher-centered approach. The instructional procedures used by the case teacher typically included lecturing based on the textbook, the students doing their assignments, and the teacher displaying and checking students' finished work. The case teacher seldom offered students opportunities to express their ideas during these processes, and where he did, he often asked questions with "yes or no" answers or about factual knowledge. For instance,

> *Teacher: What are we learning in this unit, Chen-An (not his real name).*
> *Chen-An (opens his book and reads): The decimal is multiplied by the integer.*
> *Teacher: The decimal is multiplied by the integer. Very good!*
> *Teacher: Come. Come up and cite an example question in the textbook for us to see what kind of problems we are going to solve in this unit.*
> *(Chen-An moves toward the blackboard and writes the example question on the blackboard.)*
> *Teacher: Let's see how to calculate this question.*

(The teacher works out the answer on the blackboard, and lectures on how to solve the question that Chen-An has written on the blackboard.)

Phase three: After the wireless technology was introduced into the case class and workshops were completed

The analytical results concerning the case teacher's instructional practices indicate that the case teacher's teaching method during this phase was very similar to that of Phase one. The case teacher frequently: (1) displayed the teaching materials on the e-whiteboard and lectured, (2) handed out assignments, (3) monitored students doing assignments, (4) displayed and checked students' finished assignments on the e-whiteboard, and (5) showed and lectured the correct way to solve the problem. The teacher generally applied the WiTEC modules to demonstrate and lecture materials, and seldom employed the modules to support class interaction and group work.

The case teacher's typical instruction method in the wireless environment is explained here with the following scenarios for teaching the concept of percentages.

(The teacher blacks the screens of all students' learning devices, and explains the textbook contents displayed on the e-whiteboard.)
Teacher: When the denominator of the fraction is 100, this fraction is called the percentage. [The percentage] can be used to display the part that accounts for the whole. Understand?
(The teacher shows another page on the e-whiteboard.)
Teacher: Consider this question (the teacher points his finger at the frame of the teaching material): there are two equal-sized moon cakes. Hanyu eats five-sixths of one [of the moon cakes] (the teacher writes "5/6" and circles it), and Pinyin eats four-fifths of another [moon cake], (The teacher writes "4/5" and circles it). Who eats more moon cake? All right, how did we calculate this kind of question in the past? We should expand the two fractions to a common denominator and then directly compare the size of the two.....
(The teacher continues to teach in this manner.)

In this case, the case teacher spent most of his teaching time demonstrating how to solve "percentage" problems, and spent little time allowing students to express their ideas and solve these problems by themselves. Moreover, although the case teacher assigned all students into several groups like the expert teacher in the workshop training did, he did not promote group discussion or permit students to make their notes in their tablet PCs. The teacher mostly showed his instructional materials and keys to the exercises on the e-whiteboard.

The analytical results concerning the case teacher's wireless technology applications show that the case teacher tended to use the modules that could support teacher-centered teaching. Table 3 lists the average time and percentage of time taken by the case teacher to teach specific function modules in a lesson. The following sections describe the attributes of the case teacher's technology applications that can be concluded from this table and the typewriting protocols.

Table 3. Case teacher's applications of wireless technology

	The modules		Average Time (min)	Percentage
1.	Displaying	Blacking MLD greens	20.8	71%
		Without blacking MLD greens	2.7	9%
2.		Broadcasting	0.0	0%
3.		Selective and Spot Inspection	3.8	13%
4.		Individual Learning	2.1	7%
5.		Online Learning	0.0	0%
6.		Cooperative Working	0.0	0%
7.		Integrated-response Displaying	0.0	0%
		Total	29.4	100%

- The case teacher spent on average 29.4 minutes of a 40-minute lesson teaching with the WiTEC modules.

- The case teacher spent the most time applying Module 1 to display, making notes on the e-whiteboard and lecturing (about 80% of the total time). During this process, the case teacher often blacked the screens of all students' learning devices (about 71% of the total time) and asked all students to look at what was displayed on the e-whiteboard.
- The case teacher, in general, offered students very little opportunity during lectures to learn using their own tablet PCs (about 7% of the total time).
- When the students completed the individual assignments on their own learning devices, the case teacher sometimes employed the "Selective and Spot Inspection" module to review a specific student's finished work on the e-whiteboard (about 13% of total time). However, the students were seldom offered the chance to freely express their ideas about their own completed assignments during this process.
- Four modules were not used in the technology-supported instructional activities: the "Broadcasting" module, which can enhance the utility of students' mobile leaning devices, the "Online earning" module, which enables students to access many Internet resources, the "Cooperative Working" module, which can help students work together, and the "Integrated-Response Displaying" module, which immediately displays the responses of the whole class.

Responding to the interview about the impressions and evaluations of teaching with wireless technology, the teacher approved of the "Displaying" modules, and thought that retrieving the instructional materials from the computer and taking notes on them made teaching easy.

The students' comments about learning by wireless technology. The students in the case class delivered their own learning journals a total of ten times. Table 4 presents the average numbers and average percentages of students' learning journals on each status, including the journals with positive comments only, negative comments only, both positive and negative comments, no comments, and non-delivery. The average percentage of students' learning journals with positive comments only (45.1%) was higher than that of students' learning journals with negative comments only (35.9%). These data show that the students tended to respond positively to learning with wireless technology.

Table 4. Average number and percentage of responses in student journals (n =10)

	Positive	Negative	Both	No Response	Non-delivery	Total
Number	12.6	10.0	3.5	1.5	0.4	28
Percentage	45.1%	35.9%	12.6%	5.5%	1.4%	100%

However, the frequency distributions of students' learning journals in each time period reveal that the number of students with positive comments (the sum of the number of students with only positive comments plus the number of students with both positive and negative comments) fell over time (see Figure 1). On 2/16, marking the start of Phase 3, 24 students (86% of the 28 students) made positive comments about their learning in the wireless environment. On 3/30, at the end of this phase, only six students (21% of all students) had positive comments. Conversely, the number of students with negative comments (the sum of the number of students with only negative comments plus the number of students with both positive and negative comments) generally increased over time. On 2/16, only one student (4% of all students) recorded negative comments. On 3/30, 22 students (79% of the total students) made negative comments on learning in the wireless environment.

The learning journals and the interview protocols were further analyzed to explore the possible reasons why students made these comments. The analytical results are as follows. First, most students made many positive comments on their learning with wireless technologies at the start of this phase because they were expectant and curious about learning in the wireless environment. For example, one student wrote that he was very excited and happy because he had not had the experience of using a tablet PC in class before. Another student wrote that she was very nervous and happy because it was her first time using a PC to learn. Moreover, the student wrote that she operated the tablet PC very carefully according to the steps given by the teacher, and that she hoped that she could be as happy in the next mathematics lesson.

However, as the students' experience of learning with wireless technologies increased they gradually came to realize that the real practice was less appealing than their expectations. They also thought that learning with wireless technologies had many negative aspects, such as: (1) the activities were monotonous, (2) students lacked

opportunities to operate tablet PCs, (3) students had fewer opportunities to express their own ideas than before, (4) students had fewer opportunities to perform practical mathematics tasks than before, and (5) the teacher became strict. For instance, one student wrote that learning with a tablet PC was no different from learning without one, because they were not allowed to use the tablet PCs freely. Another student declared that the teacher talked too quickly for them to understand what the teacher said. Some students stated that the mathematics lessons became very boring because the students had little time to experiment practically with mathematics and were not permitted to express or discuss the concepts.

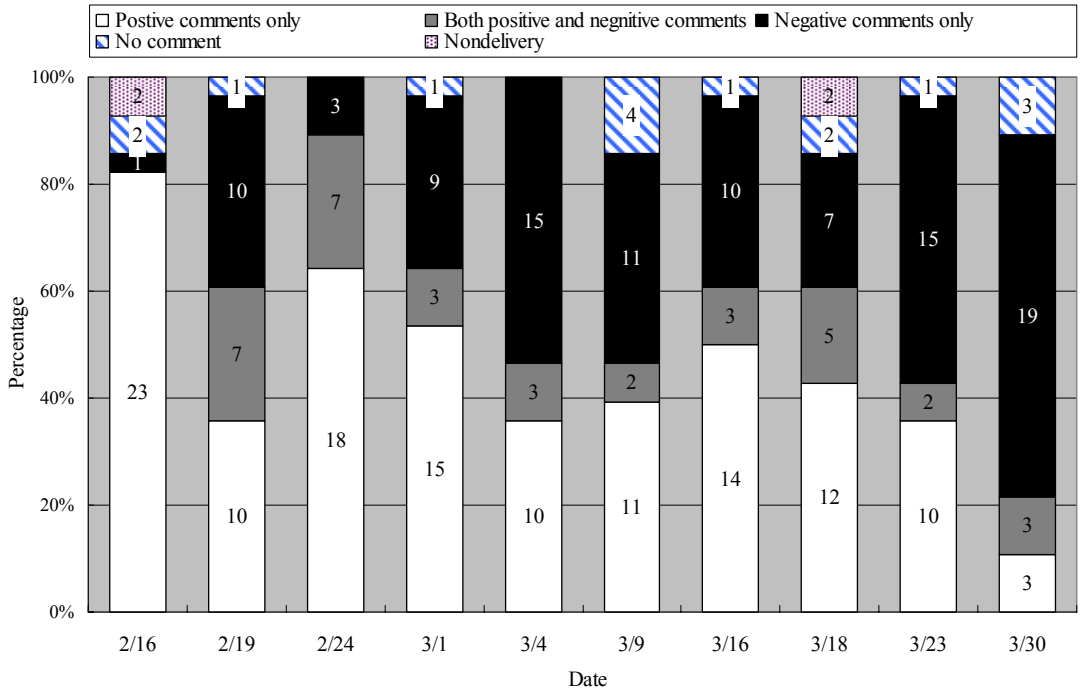

Figure1. Student comments on learning in the wireless learning environment

Moreover, the results of further analysis by comparing students' learning journals and interview protocols with the case teacher's interview protocols, indicate that: (1) the features of the case teacher's instructional activities and technology applications resulted in negative learning attitudes among the students, (2) students' negative learning attitudes further caused negative emotions in the case teacher, and (3) the case teacher's negative emotions further affected his own teaching and his students' attitudes toward learning.

Discussions and recommendations

The following sections discuss and recommend some important issues concerning the research questions and analytical results mentioned in previous sections.

Instructional beliefs

The analysis results show that the case teacher's instructional practices, with or without wireless technologies, were inconsistent with his instructional beliefs. Before the current study started, the case teacher had already expounded the importance and soundness of the learner-centered instructional approach and of IT applications in the classroom, and expected to play the role of guide or promoter to improve students' learning. However, the case teacher's real instructional practices tended to be teacher-centered rather than learner-centered in both the ordinary classroom and

when in the wireless environment. The case teacher often lectured, and seldom allowed students to express their ideas, handle experiments, operate the tablet PC, or perform group work.

This case is consistent with some earlier studies that indicated that teachers' instructional practices do not always conform to their beliefs (Thompson, 1992; Raymond, 1997; Wilson & Goldenberg, 1998), especially for teachers whose beliefs correspond to mainstream perspectives and social expectations. The study of Wilson & Goldenberg (1998) indicated that most teachers who participated in educational reforms "generally held reform-based views of mathematical learning and instruction." However, these "reform-minded teachers did not seem guided by their beliefs when making instructional decisions" (p. 227).

Furthermore, some other researchers have proposed reasons why teachers' instructional practices may not be consistent their own instructional beliefs. Fang (1996) noted that the teacher beliefs surveyed by the interview or self-reporting, "… may reflect what should be done rather than what is actually done in class" (p. 53). Teachers could express their own ideas with fervor and assurance outside the classroom, but their real instructional decisions and classroom behavior are often governed by their instructional routines and the classroom contexts (Duffy & Anderson, 1984).

In summary, the teachers with positive attitudes about learner-centered approaches and technology applications may attempt to apply the wireless and mobile technologies in their classroom (just as the case teacher did). However, the teachers who approve of the learner-centered approach but teach in the teacher-centered way may start to confront problems after the wireless and mobile technologies are fully introduced into the classroom. Therefore, teachers' beliefs, especially when surveyed by interview, are not the most appropriate index to predict teachers' actual practices when implementing innovative technology.

Instructional routines

The instructional routines of the case teacher significantly restricted his teaching approach in the wireless learning environments. This study found that the case teacher's instructional practices and decisions were not freed from existing teacher-centered routines, even though the wireless learning environment had the potential to support students' active learning and group working, and even where the case teacher had positive attitudes to learner-centered teaching and IT application.

The case teacher preferred to adopt innovative technologies fit in with his existing instructional routines when employing wireless technology in a real classroom. The case teacher tended to use wireless environment modules that could support teacher-centered teaching, and avoided applying those that required students to actively operate their own tablet PCs. For instance, the case teacher liked to employ the "display" module to support his lectures. Furthermore, even when the teacher used the "Selective and Spot Inspection" module to display the students' finished assignments, he spent most of his time correcting students' assignments, without offering students the chance to express their ideas.

Close attention needs to be paid to the classroom roles and rules, because they mediate the usage of mobile and wireless technologies (Penuel et al., 2004). Earlier literature found that teachers often teach with innovative technologies in their familiar way, but without using these technologies fully or effectively. For example, one of the challenges hindering widespread adoption of handheld-centric classroom is that teachers who use handhelds are not using the student-generated documents as primary assessment instruments, as experts suggest, but are instead using handhelds simply as just a substitute for paper (Norris & Soloway, 2004).

Teachers' instructional routines can affect their teaching approach with innovative technology. Observing teachers' instructional behavior is not only a useful way to study teachers' real-life practices, but is also necessary to understand the teachers' existing instructional routines and to find possible obstructions to introducing novel programs or technology into classrooms.

Wireless learning environment

Wireless and mobile technologies cannot effectively change the case teacher's instructional practices. Wireless technology has many features which benefit the implementation of learner-centered instruction. However, technology cannot "automatically cause" changes in teachers' instructional practices (Dexter et al., 1999, p. 236), and the technology itself cannot help teachers move from a teacher-centered to a student-centered approach (Greenberg et al., 1998).

Introducing wireless learning environments into the classroom placed the case teacher in a dilemma: the case teacher needed to change the instruction to fit the features of the innovative technology, but this change caused stresses. Fully adopting the features of the wireless and mobile technology required the case teacher to make significant changes from familiar instruction, thereby causing significant changes in classroom phenomena, such as types of classroom interaction, social relationships between class members, and the nature of teaching materials and assignments. Such major changes caused unfamiliarity, uncertainty, and complexity to the case teacher, and made him feel stressed.

Moreover, wireless and mobile technologies do not solve general problems in the classroom, and might cause new ones (Penuel et al., 2004). Wireless learning environments are like a double-edged sword. For instance, wireless mobile devices help students to access online resourses and communicate with other people, but may also distract students from the teacher's lecture for this reason (Roschelle, 2003). These potential problems also cause the case teacher to be hesitant.

These strong stresses and misgiving still prevented the case teacher from altering his teaching approach, even when the case teacher was aware that his students disliked his method of teaching with wireless technology. Hence, the case teacher preferred to employ the modules that conformed to his familiar instructional approach, rather than adopt the modules requiring changes in his teaching. For example, when being interviewed about why he often blacked the screens of students' learning devices in Phase three, the case teacher answered: "When I am teaching, I don't like my students to use their own devices…If they use their own devices, I cannot control what they do, since I don't even know whether my students listen to what I am saying…I think if I allow students to use their [tablet] PCs freely, then the situation will be more complex."

The study results indicate that future studies should design some useful functions to help teachers fully benefit from the features of wireless learning environments and avoid stress and concerns when developing wireless learning environments. For instance, classroom management functions that help teachers monitor student activities on learning devices without disturbing students' personal privacy are imperative..

The reciprocal effects

Teacher's instructional routines, wireless technologies, and students' expectations caused negative reciprocal effects among the technology, teaching, and learning. Although earlier evaluations found that the mobile devices have the potential to excite students and positively affect students' learning (Swan, et al., 2005), these results were achieved partly because these teachers allowed the students to utilize their own learning devices (such as taking notes, managing personal information, drawing pictures, and transferring files to other devices) to support personalized or cooperative learning (van't Hooft et al., 2004; Swan, et al., 2005).

The student-centered features of wireless technology, and the case students' expectations of using it, gave most students positive attitudes toward learning in a wireless learning environment when the wireless environment was initially introduced to the case class. However, the case teacher persisted with a teacher-centered instructional approach without providing students with chances to operate their own devices, express their ideas, and implement mathematical experiments, disappointing the students and causing their attitudes toward learning to gradually change from positive to negative. Additionally, the students' negative learning attitudes led to increasingly inappropriate class behavior, such as decreased attention and interest during the teacher's lectures, and a failure to hand in assignments on time. This inappropriate behavior negatively affected the case teacher's teaching mood, and hence his instructional behavior.

The negative reciprocal effects among technology, the case teacher's teaching, and the students' learning occurred through these processes because the case teacher maintained his existing instructional routines, which could not match either the features of wireless technology or the students' eager expectations.

Teacher professional development and support

Although the professional development of teachers is not the primary focus of the study, it must still be considered. The study results indicate that the workshop trainings, used to familiarize participants with wireless technology-based collaborative learning activities through observation and manipulation, cannot effectively support the case teacher in changing his own instructional practices. The results of earlier studies may provide some possible reasons for this study result. First, although the case teacher had many chances to observe the experts' teaching demonstrations, which implemented wireless technology-based collaborative activities, he was given few opportunities to understand the experts' thinking and decisions in these implementation processes. Greenberg et al. (1998) pointed out that such workshops were not enough to prepare teachers, particularly inexperienced users of technology, for teaching with technology. The inexperienced users of technology generally did not transfer what they had learned in the workshop into the classroom.

Furthermore, the workshops in this study adopted the top-down dissemination model based on one-shot workshops, with lists of prescribed practices to be observed and implemented, and no on-site support. Some studies have pointed out that such workshops cannot implant changes or sustain innovation (Hall & Hord, 1987; Kaestle, 1993).

Finally, although the principal and the administrators were all willing to provide support and help to the case class, unfamiliarity with the innovative technology and its applications meant that these help providers could not appreciate the problems that the case class confronted, and thus were unable to help effectively. Teachers who attempt to teach in wireless learning environments in the future should have the support of the entire learning community.

This study recommends that future teacher-development programs should try to guide teachers who use technology with a teacher-centered approach toward a more learner-centered approach. This change should be made gradually, because change is a source of stress that often makes teachers retreat to their familiar instructional practices. Moreover, teachers who agree with the student-centered approach but adopt a teacher-centered teaching style may encounter frustration when they actively attempt to teach in wireless environments. Because of this, the teacher-development program must provide these teachers with effective pedagogical and technological support to reduce the gap between their beliefs and their actual practices. Furthermore, teachers are themselves learners when innovative technology is introduced to classrooms. Earlier empirical study results (Liu, 2005) have revealed that effectively integrating technology and learning models (such as the cognitive apprenticeship model) can enhance teachers' professional development. Finally, teachers using teacher-centered instructional routines require adequate on-site guidance to help them to plan, teach, and reflect upon their teaching in wireless learning environments. For instance, after the current study ended, the researcher discussed classroom observations with the case teacher. The researcher also provided the framework for the expert teacher's decision processes within the wireless learning environment in order to guide the case teacher to plan, teach, and reflect upon his teaching with wireless and mobile technologies. The initial results revealed that this guidance and assistance was effective in changing the case teacher's instructional practices, promoting the students' positive learning attitudes, and benefiting the case teacher and students in the wireless learning environment (Liu, preparing). The case teacher has now become his school's seed teacher for promoting the educational application of wireless and mobile technology.

Limitations of this study

Although using a case with a single class and teacher enabled this study to explore some significant issues in depth and over the long term, it also affected the generalization of the results. Further studies with various case classes (or case teachers) and with different methods, such as a field experiment, are recommended.

Furthermore, this case study has identified some issues that require further study, such as the impact of teachers' use of wireless technologies to influence student learning, possible support of teachers' organized learning communities, and the influence of the type of training and support for teachers teaching with wireless technologies. Clarifying such

issues can improve the understanding of how to help teachers effectively integrate wireless technologies into their teaching.

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Appendix A: The interview questions with the case teacher

Teacher's beliefs about instruction

1. Please illustrate your perspectives about teaching.
2. Please illustrate your perspectives about the role that teachers should play during teaching.
3. Please illustrate your perspectives about the role that students should play during learning.
4. Please illustrate your perspectives about the teacher-student interaction.
5. Please illustrate your perspectives about classroom management.
6. Please illustrate your perspectives about the relationship between the teacher and students.

Teacher's belief about educational application of technology

1. Please illustrate your perspectives about wireless and mobile technology.
2. Please illustrate your perspectives about integrating technology into teaching.
3. Please illustrate your perspectives about the role that technology should play during teaching.
4. Please illustrate your perspectives about the relationship between technology and teacher-student interaction.

Appendix B: Phases and tasks of WiTEC-based collaborative learning activities

Phase	Principal instructional tasks
Improving students' preparation	1. Adopting the e-whiteboard to show and explain materials to students. 2. Adopting the "Integrated-response Displaying" module to monitor students' understanding of the teacher's illustration.
Monitoring and supporting group work	Guiding students to implement activities, including: 1. Adopting their own tablet PCs to read and note the learning materials and to explore and access more learning resources on the Internet. 2. Sharing and discussing information with other group members. 3. Progressively building a common view of their group tasks, through the reciprocal process of exploring, collecting, sharing, and discussing. 4. Adopting the "Cooperative Working" module to recording, arranging, integrating and revising the group's report.
Guiding groups' presentations and implementing evaluations	1. Guiding each group to demonstrate its own finished report on the e-whiteboard and discuss with the whole class; 2. Noting and checking each group's report, and broadcasting it to each student's learning device); 3. Adopting the "Integrated-response Displaying" module to implement the formal assessment or peer-evaluation and understand students' learning statuses and opinions.