Improving Mathematics Teaching and Learning Experiences for Hard of Hearing Students With Wireless Technology-Enhanced Classrooms

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IMPROVING MATHEMATICS TEACHING AND LEARNING EXPERIENCES FOR HARD OF HEARING STUDENTS WITH WIRELESS TECHNOLOGY–ENHANCED CLASSROOMS

HARD OF HEARING STUDENTS usually face more difficulties at school than other students. A classroom environment with wireless technology was implemented to explore whether wireless technology could enhance mathematics learning and teaching activities for a hearing teacher and her 7 hard of hearing students in a Taiwan junior high school. Experiments showed that the highly interactive communication through the wireless network increased student participation in learning activities. Students demonstrated more responses to the teacher and fewer distraction behaviors. Fewer mistakes were made in in-class course work because Tablet PCs provided students scaffolds. Students stated that the environment with wireless technology was desirable and said that they hoped to continue using the environment to learn mathematics.

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The Ministry of the Interior of Taiwan estimates that around 912,000 people in Taiwan are mentally or physically challenged, of whom about 97,000 individuals are deaf or hard of hearing. Hard of hearing students usually face more difficulties at school than other students, which leads to low levels of learning performance. Wireless technology can enhance opportunities for students to learn and to improve their learning activities with enhanced communication and computation capacities. Unfortunately, access to learning assistance based on wireless technology addressing the requirements of hard of hearing students in classrooms is still very restricted.

As a fundamental and indispensable competence, mathematics is a main subject in K–12 education. Nunes and Moreno (2002) note that deaf and hard of hearing students generally are not exposed to many opportunities to learn mathematics. This results in information deprivation, originally explained by Furth (1966) and Rapin (1986), and lower achievement. In addition, the language ability of deaf students has been considered the critical factor in their difficulties with mathematics (Pagliaro & Ansell, 2002). Therefore, network technology has been used to provide Web-based instruction and guided practice to improve mathmatics word-problem solving by deaf and hard of hearing students (Kelly, 2003).

In addition to language ability, the quality of student-teacher communica-

tion affects the mathematics learning of deaf and hard of hearing students. The teachers cannot easily lecture on basic mathematical concepts to deaf or hard of hearing students in sign language or via interpreting (Adamo-Villani, Doublestein, & Martin, 2005). Therefore, such students cannot easily understand lectures, and cannot easily express complex mathematical expressions. This makes effective interaction with teachers difficult. Accordingly, mathematics teaching has to be concerned with enhancing student-teacher interaction, reducing the cognition load of hard of hearing students, and enforcing reflective learning and assessment.

The difficulty of teacher-student interaction that confronts students with hearing loss appears to be unavoidable during in-class learning activities. Sign language and hearing aids can only slightly reduce this difficulty. Smith and Ramsey (2004) indicate that teachers who lecture in fluent sign language do not generally achieve an effective teaching performance. Even students who wear hearing aids or use cochlear implants cannot overcome the interaction problem between the teacher and the students. Smith and Ramsey suggest that teachers must make a significant effort to interact with hard of hearing students and encourage them to participate actively in learning activities.

Researchers have reported on difficulties experienced by hard of hearing students in mathematics learning (Kelly & Davis, 2003; Mousley & Kelly, 1998). Feuerstein (1980) addressed the requirement to restrain impulsive learning behaviors when mediating problem-solving processes of hearing students. Similarly, hard of hearing students tend to generate intuitive solutions quickly and make errors easily when working on mathematics problems (Meadow & Schlesinger, 1971; Mousley & Kelly, 1998). Additionally, hard of hearing students cannot clearly and accurately receive learning content, and frequently have to guess about the content of teachers' lectures in class. Hence, hard of hearing students have heavier cognition loads than hearing students. Thus, one challenge in improving hard of hearing students' learning performance in mathematics is to provide them with appropriate learning aids to restrain impulsive behavior, solve mathematics problems, and reduce their cognition load.

Learning assessment is an integral component of teaching and can strengthen the effect of learning. Black and William (1998) point out that assessment in class gives learners feedback, significantly affecting learning performance. However, hard of hearing students cannot easily discover their mistakes if the teacher merely demonstrates how to solve mathematical problems to all students on the whiteboard without giving each student direct and instant feedback. Meanwhile, as teachers evaluate students' course work separately, they will encounter communication problems concerning how to share the evaluation process with other students to ensure that no student is excluded. Therefore, a challenge faced by teachers is to overcome the communication barrier to make assessments effectively and dynamically, thus enabling students to participate in all evaluation processes and thus increasing their opportunities for self-reflection.

Information technology has been increasingly applied to help hard of hearing students learn. Jaklic, Vodopivec, and Komac (1995) designed teaching software to help hard of hearing individuals actively learn sign language through multimedia interaction. Passig and Eden (2000) used virtual reality technology to improve flexible thinking in hard of hearing children. Barman and Stockton (2002) applied multiple information technologies such as the World Wide Web, videoconferencing, and FTP (file transfer protocol) to help teachers and deaf students located in different places work collaboratively on earth science investigations. Gentry, Chinn, and Moulton (2005) used computers to present stories with multimedia as an interesting supplement to enhance reading comprehension. In the present study, we attempted to integrate computers, wireless technology, and learning activities to improve day-to-day learning in classrooms for hard of hearing students.

The present study explored whether wireless technology, including wireless network and Tablet PCs, can augment student-teacher interaction, reduce cognition load, and facilitate formative assessment. To answer this question, a WiTEC (wireless technology–enhanced classroom) environment combining Tablet PCs, a wireless network, and software applications was developed to facilitate mathematics teaching and learning activities based on the requirements of the hard of hearing students in a self-contained classroom (see Figure 1).

Technical Supports for Facilitating Mathematics Lectures

There are 2,855 deaf and hard of hearing students studying in kindergarten, elementary school, and junior high school in Taiwan (see Table 1). Of these students, 14.9% study in centralized schools of deaf education and 13.1% study in self-contained classrooms in regular schools. Most deaf and hard of hearing students (72.1%) are integrated with hearing students in inclusive classrooms. However, schools must provide resource classes for deaf and hard of hearing students who learn in inclusive classrooms.

Figure 1
Instruction and Learning with Tablet PCs and a Wireless Network

The resource classes are designed to augment the teaching in inclusive classrooms so as to assist students in learning language and mathematics. Therefore, deaf and hard of hearing students generally learn mathematics in separate classes in Taiwan.

There are few deaf and hard of hearing teachers in Taiwan. In addition, Hsing (2003) found that only the teachers in centralized schools of deaf education applied Simultaneous Communication, or SimCom (with both sign and oral language) to teaching in Taiwan. Hsing also found that 41% of these teachers could not teach effectively using the SimCom method. These results are consistent with those of an earlier investigation, by Chang (1996). Chang indicated that 88% of teachers in self-contained classrooms and resource classes in regular schools taught orally. She also found that 82% of teachers demonstrating the use of sign with oral language in Taiwan did not facilitate the reading of speech and sign. Therefore, a challenge in improving mathematics learning in Taiwan is to promote student-teacher interactions during in-class teaching activities.

Many studies have proposed pedagogical approaches to teaching mathematics to hard of hearing students. For example, Mousley and Kelly (1998) suggested a pedagogy that uses peer observation and process visualization tools to enhance the problem-solving performance of deaf and hard of hearing college students. However, in the present study, use of the WiTEC environment was not restricted to support of a specific pedagogy. Instead, the WiTEC environment was designed to support a general pedagogy based on Davis's general instruction stages (Davis, 1981), that is, introduction, development, and consolidation (IDC).

In IDC-based instruction, the teacher introduces the significance of a lesson in the introduction stage to stimulate students' learning motivation, and further to explain the goal and key points to develop students' general understanding of the issues they will learn. The teacher demonstrates the learning content or skill to develop students' knowledge in the development stage. In the consolidation stage, the teacher guides the students to practice examples. The teacher then evaluates the students' work, and encourages the students to advance their study or apply the knowledge they acquire to their lives.

Teachers need technical support when applying the three instruction stages to mathematics instruction. In the introduction stage, the teacher has to undertake interactive activities such as question and answer to motivate students to learn. Therefore, teachers and students require convenient communicative aids for interaction. In the development stage, the teacher must demonstrate examples relating to the lecture contents and interact with students to ensure that they understand the entire lecture. Additionally, the teacher must prepare learning scaffolds to guide the learners to imitate and exercise for the consolidation stage. Students then imitate the teacher's process illustrated by the scaffolds to force them to work carefully on their course work. Therefore, teachers need a convenient shared whiteboard and tool for demonstration and for preparing scaffolds at the development stage. Additionally, to increase the opportunity for students to reflect on their course work, teachers need support to share student course work and evaluation process while assessing course work.

The wireless network and Tablet PCs in a WiTEC environment can help teacher and students improve the teaching and learning activities in all three stages. For the present study, use of a shared whiteboard on Tablet PCs was implemented. In this approach,

Table 1
Distribution of Deaf and Hard of Hearing Students in the Taiwan Education System

	Centralized schools	*Self-contained classrooms*	*Inclusive classrooms*
Kindergarten	109 (3)	44 (7)	300
Elementary school	169 (3)	196 (27)	1,131
Junior high school	146 (3)	133 (17)	627
Total	424	373	2,058

Notes. N = 2,855. The numbers in parentheses indicate number of schools.

the teacher lectures on the shared whiteboard using the stylus of the Tablet PC, and projects the shared whiteboard onto a large screen. The hard of hearing students can ask questions, respond to the teacher's queries, and solve mathematical problems using their Tablet PCs and styli. All the questions, queries, responses, and course work can be transmitted to the teacher's Tablet PC and projected onto the shared whiteboard. A scaffold component records all the steps performed by the teacher to solve a mathematical problem as part of the learning scaffold for the consolidation stage. The learning scaffold then shows learners the crucial step to solving the mathematical problem. The students can then follow the teachers' steps on their Tablet PCs to solve a mathematical problem. Moreover, students can also transfer their course work to the teacher's Tablet PC via the wireless network. Teachers assess student course work instantly, and show all the assessment processes on the shared whiteboard to fulfill formative assessment. Table 2 displays the technological support required for lecturing and learning activities in the introduction, development, and consolidation stages.

The Wireless Technology–Enhanced Classroom for IDC Activity

The emergence of wireless technology implies that the wireless network and handheld devices are extensively adopted in daily life. Handheld devices such as personal digital assistants (PDAs) and Tablet PCs provide convenient input interfaces that enable students and teachers to undertake their learning and teaching activities using styli instead of traditional keyboards. Furthermore, wireless networks allow teachers and students to connect to the Internet without network cables. Such developments enable realization of the wireless technology–enhanced classroom, or WiTEC (Chen, Juang, Feng, Chou, & Chan, 2004). In a WiTEC environment, teachers use handheld devices including wireless networks, multimedia material, Tablet PCs, and PDAs to interact with students.

Many researchers have implemented WiTEC environments to improve learning and teaching in various learning scenarios. For instance, Chen, Kao, and Sheu (2003) adopted PDAs and wireless networking to create a WiTEC environment for an outdoor learning activity in which students learned the ecology of birds by using PDAs to take snapshots and ask for information about birds. Additionally, Willis and Miertschin (2004) pointed out that Tablet PCs can be used in the classroom to fulfill the functions of note taking, presentation creation, document markup, and information management because the handwriting interface of Tablet PCs allows students and teachers to write characters and symbols conveniently using a Tablet PC stylus instead of a keyboard. Richard Anderson and colleagues (2004) used Tablet PCs with styli combined with a slide show for lecturing and learning activities. They confirmed that using Tablet PCs and styli for teaching and learning helps students remain attentive to learning activities and improves understanding of course content. Therefore, instead of using the general-purpose personal computers, students can perform learning activities with convenient and easy-to-use learning facilities in a WiTEC environment.

In the present study, a WiTEC environment with wireless technology was implemented as an aid to communication for a hearing teacher and her seven hard of hearing students in a self-contained class in a regular school. These students communicated with each other and the teacher orally, although they could sign to each other. The WiTEC environment included Tablet PCs and a wireless network, and used software components to support learning activities at the different IDC stages.

A Tablet PC is an ultramobile laptop computer with a convertible screen that can be used like a tablet, with a stylus and on-screen keyboard input. The teacher writes and presents teaching contents or questions by using a stylus, while students write remarks on the questions they do not understand, or answer the teacher's query. All answers can be transmitted to teachers through the wireless network. The teacher evaluates student results on the Tablet PC screen directly, then demonstrates the process on the projector to all students, thus implementing formative assessment. The WiTEC environment also offers a scaffold tool that demonstrates examples step by step to solve mathematical problems in order to reduce students' cognition load.

Figures 2 and 3 illustrate the scenario of teaching and learning in the

Table 2
Activities and Technical Support for the IDC Stages

Instructional stage	*Lecturing and learning activity*	*Technical support*
Introduction	Stimulating motivation, outlining topics, interactive activity	Shared whiteboard
Development	Example demonstration	Scaffold tools
Consolidation	Imitating, practicing, sharing course work, assessment	Scaffold tools, assessment tool

Note. IDC, introduction, development, consolidation (Davis, 1981).

WiTEC environment. The teacher and hard of hearing students are all equipped with a Tablet PC in the classroom. The teacher's Tablet PC is connected to the projector to show her screen. All the Tablet PCs are instantly linked to each other through wireless access points, which form the wireless local network for sending learning materials, course work, questions, instruction, and assessment processes as an interactive and communicative aid between the teacher and students.

Software Components for Tools Used in the WiTEC Environment

Shared Whiteboard

The shared whiteboard provides communication support for introductory activities such as stimulating motivation, outlining topics, and questioning and answering, and is designed to improve the interaction between teacher and students. When the teacher undertakes the introduction activity, her projector, connected to the Tablet PC, projects all the material to the projector screen, and the shared whiteboard installed at her Tablet PC snatches the screen of the teacher's Tablet PC and sends it to the students' Tablet PCs via the wireless network. However, students do not simply stare at their Tablet PCs, because the shared area is still on the screen at the front of the classroom. The content of students' screens is the same as that of the teacher's screen, helping students conveniently ask questions or answer the teacher's questions via stylus.

Figure 4 depicts the shared whiteboard during a question-and-answer activity between teacher and students. The left image indicates that a student asked a question about the "ay" in the material being lectured on by marking it with his Tablet PC stylus. The student then transmitted the question to the teacher across the wireless network.

Figure 2
Instruction and Learning Scenario in a WiTEC (Wireless Technology–Enhanced Classroom) Environment

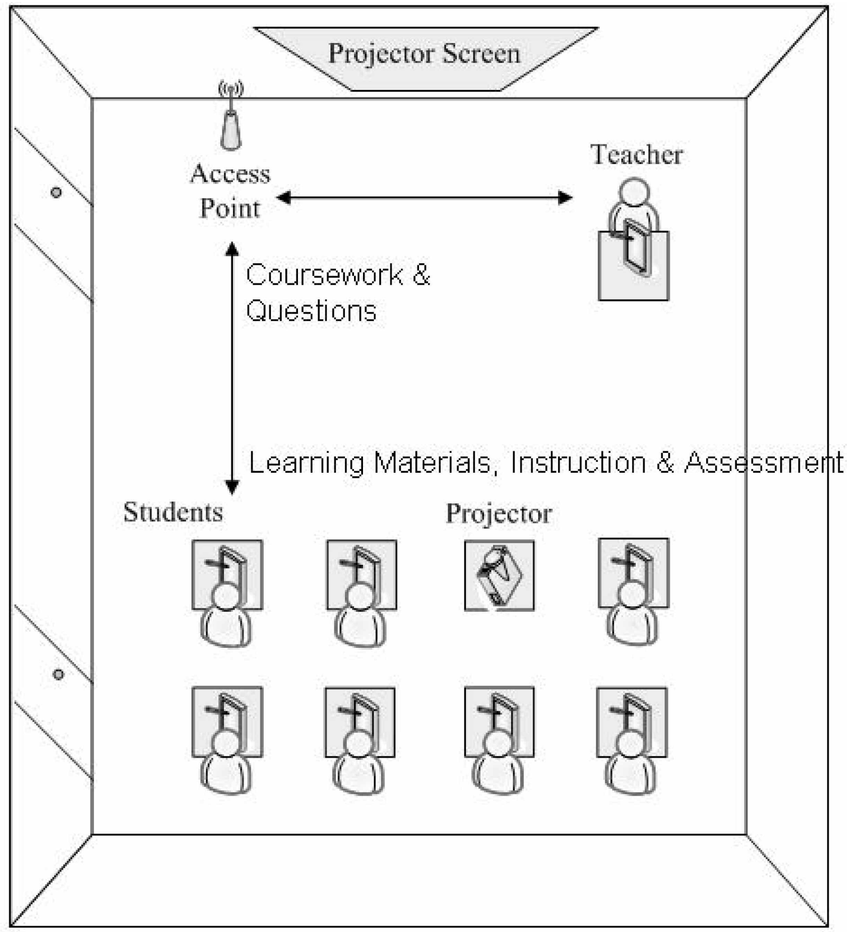


Figure 3
Snapshot of Instruction and Learning in a WiTEC (Wireless Technology–Enhanced Classroom) Environment

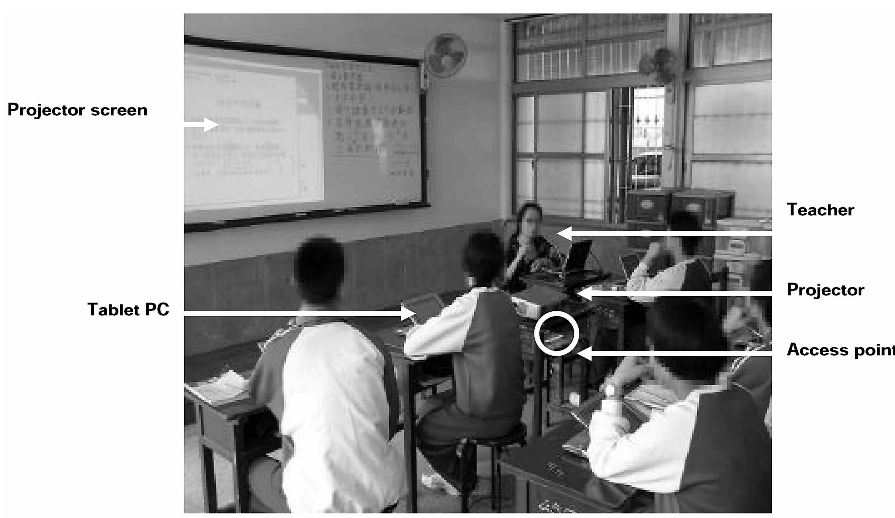
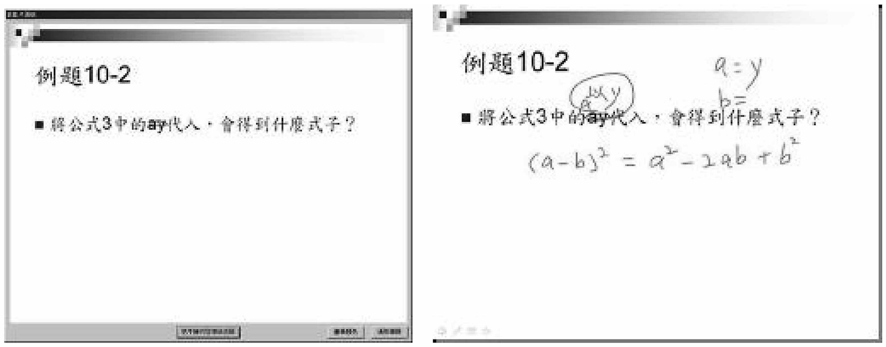


Figure 4
Question-and-Answer Activity Using Shared Whiteboard



The screen on the teacher's Tablet PC instantly became the same as that on the student's Tablet PC as student passes the question to the teacher. The image on the right side shows the teacher's explanation made with Tablet PC stylus to answer the student's question. All the processes are shown on the projector screen. Therefore, the shared whiteboard can be used as a communicative tool when students are required to answer questions during class.

Scaffold Tools

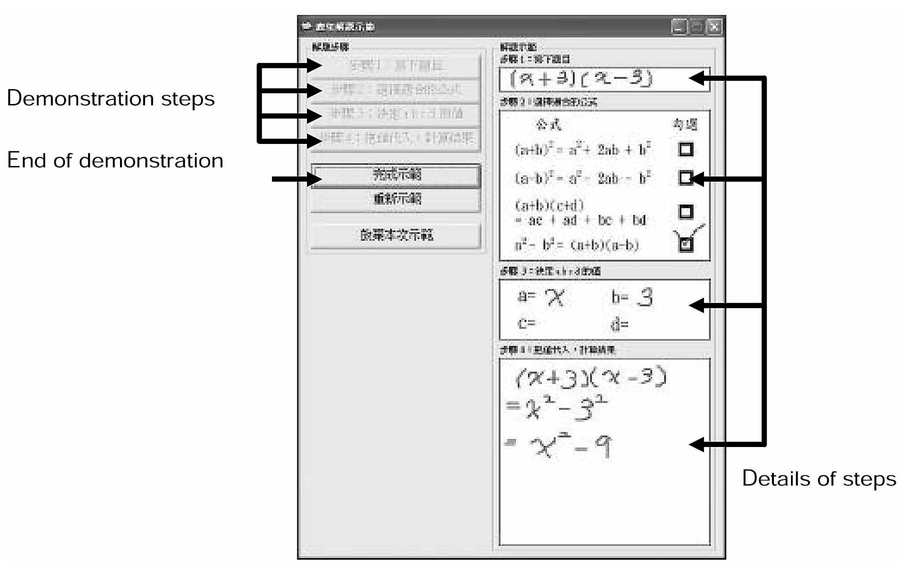
Scaffold tools provide hard of hearing students with the guidance to do course work and, further, to prevent them from answering questions impulsively. For the present study, the scaffold tools at Tablet PCs were developed for the teacher to prepare scaffolds, and for the students to do course work directly with the Tablet PCs stylus and the teacher's scaffolds.

Scaffold tools support the activities of the development and consolidation stages, including demonstrating examples and practicing course work. The tools enable the teacher to divide a complicated mathematical problem into simple steps, which help students solve similar problems, thus reducing cognition load. The teacher sets up the steps and explains the solution of each step when she demonstrates the solution of a complex mathematical problem. Figure 5 shows the snapshot of the scaffold tools, with the teacher applying a Tablet PC stylus to explain the steps to solve a complicated problem by sequentially clicking the step buttons on the top-left side. The system has a sequential block with the required materials on the right side of the screen for the teacher to explain the solution in each step. All the steps and explained solutions are recorded by the scaffold tools. Students can then solve similar problems by following the steps demonstrated and recorded by the teacher.

The entire process of problem-solving demonstration is one component of teaching. All the problem-solving and scaffold preparation processes are projected onto the projector screen. The teacher not only completes scaffold preparation while clicking on every step's button and writing down the solution, but also orally explains the solution or asks for students' responses. For instance, the teacher can ask students, "Here we are; what is the next step?" or "Pay attention to the step; which formula should we choose to apply?" The teacher conveniently lectures and demonstrates examples with the blackboard. The computational power of Tablet PCs further records all the steps to scaffold students' problem solving while helping the teacher to lecture clearly, much as a blackboard does.

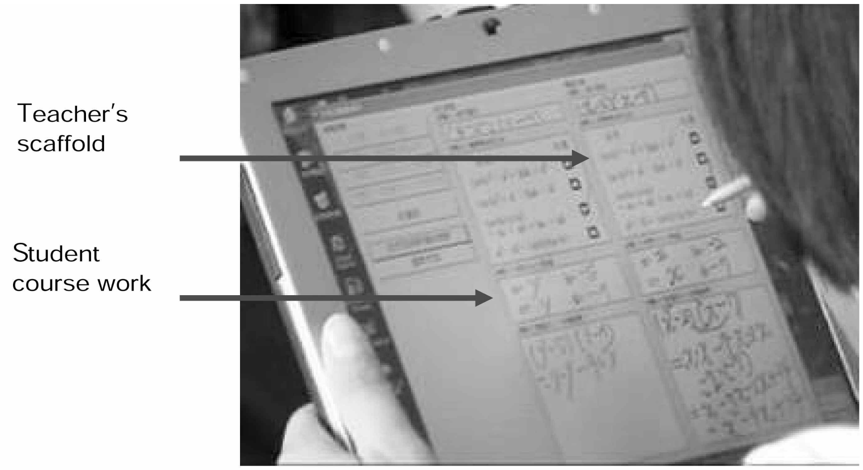
After the example demonstration and scaffolding preparation are finished, the teacher clicks on the "end of demonstration" button, and the scaffold tools broadcast all the steps and the details of these steps to each student's Tablet PC through the wireless network. The steps and process of problem solving conducted previously by the teacher are opened automati-

Figure 5
Example Demonstration and Scaffold Preparation



cally at each student's computer. The system opens an input block for students to solve a new problem. Meanwhile, the step of problem solving previously shown by the teacher pops up in sequence, as displayed on the right side in Figure 6. Students can solve the new problem following the steps taken by the teacher.

Figure 6
A Student Solving a Problem With the Scaffold Prepared by the Teacher



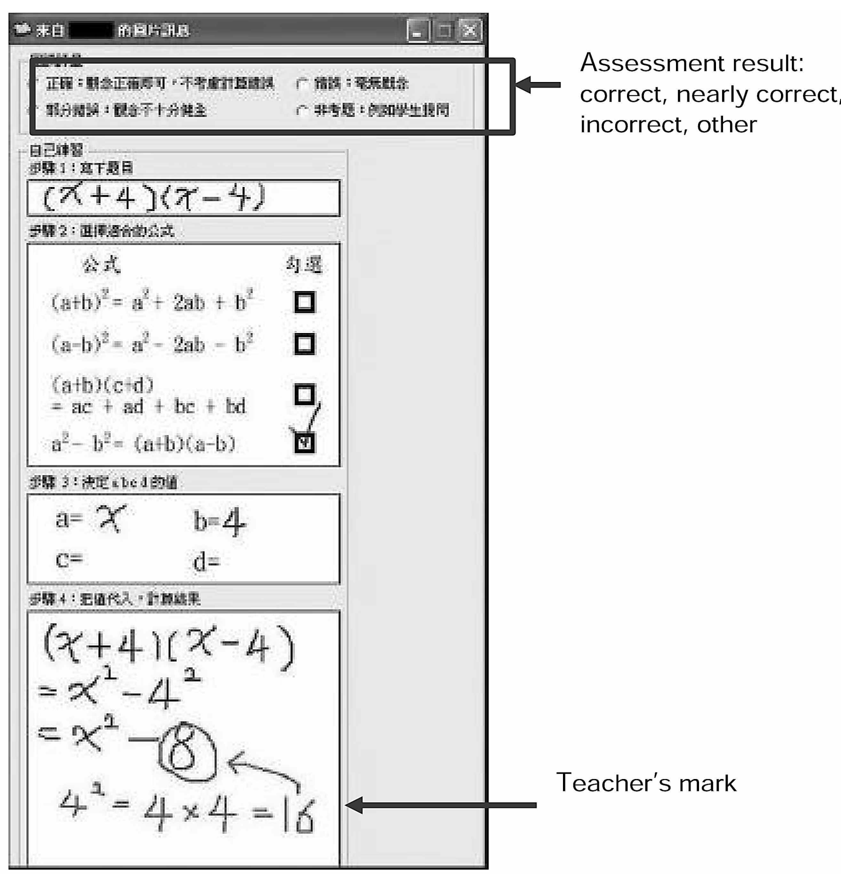
Assessment Tool

The assessment tool provides an interface for the teacher to assess the results of students' course work. The course work can be explained and corrected immediately after the development activities. The teacher encourages students to practice the corrected exercises repeatedly, and also repeatedly evaluates and corrects results. The assessment tool supports individual and formative assessments in which the teacher dynamically assigns problems to students and evaluates student course work immediately after it is submitted. In the WiTEC environment, the teacher dynamically amends the errors made by students to point out their mistakes clearly. Notably, all of the process of evaluating is displayed on the screen through the projector, enabling all students to see how the teacher corrects their own errors and the mistakes of others.

The students can obtain effective assessment directly from the teacher as she evaluates each student's course work on the Tablet PC. Moreover, students who finish course work early can immediately interact with the teacher, shortening the time that they are kept waiting, and reducing the possibility that they will become idle and distracted.

Figure 7 illustrates the application of the assessment tool. The tool provides the teacher with functions for determining whether the submitted answers are completely correct, partially correct, or totally incorrect. Additionally, the tool provides the whole content of student course work and helps the teacher use the Tablet PC stylus to correct and explain the results from students. The entire assessment process proceeds on the teacher's computer and is projected onto the projector screen. All the students not

Figure 7
Snapshots of Use of the Assessment Tool to Support Dynamic Assessment



only view how their course work is assessed but also observe all the mistakes made by others.

The Experiment

An experiment was conducted to explore the effectiveness of the WiTEC environment for improving learning and teaching experiences. The experiment involved seven hard of hearing junior high school students who were learning geometry and polynomials. The mathematics capacity of these seven students was middle and lower level. Fifty questions from the competence test of mathematics for Taiwanese hard of hearing students (Lin & Li, 1996) were adopted to measure the students' mathematics capacity. They were found to rank from the 22nd to the 63rd percentile among students in the second year of junior high school in Taiwan. An ethnographic and questionnaire analysis was undertaken to examine student reactions to the WiTEC environment. Students' participation and course work performance were expected to improve in the WiTEC environment.

Research Questions

There were three research questions: (a) Did the WiTEC environment improves the interaction between the teacher and hearing impaired students? (b) Did the scaffold tools in Tablet PCs enhance the mathematical problem-solving processes of hard of hearing students? (c) Did the hard of hearing students accept the WiTEC environment as an aid in learning mathematics?

The experiment lasted two semesters. In the first semester, the WiTEC environment was introduced to the teacher and students, who began to use the environment and software tools in mathematics class and become familiar with the Tablet PCs and tools. The teacher taught geometry in four lectures before the end of first semester. The main teaching subject was the equation $y = ax + b$ in two-dimensional coordinates. The teacher lectured with the WiTEC environment twice during the four lectures, and used only a whiteboard and textbooks without any other technological support in the other two lectures. The teacher lectured on polynomials four times in the second semester. Two of the four lectures were conducted with the WiTEC environment and software tools; no technological support was used in the other two. The student and teacher behaviors during the eight lectures were videotaped and analyzed.

Student-Teacher Interaction

The eight lectures under two different teaching conditions were analyzed to understand how the WiTEC environment affected the student-teacher interaction. Three behaviors during the lectures were investigated:

- *Question response frequency*: the frequency of students' responses to the teacher's questions. For instance, the teacher frequently asked, "What is the value of 4 over 2?" or "Where is the point (4, 0)?" The students could answer the teacher's questions accordingly.
- *Status response frequency*: the frequency of students' responses to the teachers' query about student status. For example, the teacher might ask the students "Understand?" or "Any questions?" Some students would nod their heads or utter a word in response. If no one responded physically or orally at all, then the teacher would repeat the explanation and ask the students again to ensure that they had no problem with the current instruction.
- *Frequency of distraction*: how often the hard of hearing students were idle, turned their heads to stare out the window, or began chatting with others in sign language or passing notes.

Table 3 lists the number of teacher's questions and students' reactions to these questions in two different conditions. The WiTEC environment engaged students to respond the teacher's questions. The teacher got no response to only 8.3% and 6.3% of questions, respectively, in the two lectures in the WiTEC setting. By contrast, she got no response to 43.8% and 42.9%, respectively, of questions in the non-WiTEC setting. Students were waiting for the teacher's next action, such as changing the question or telling them the answer straightaway. However, the WiTEC environment increased the percentage of questions to which several students responded. The proportions of the questions to which students gave multiple responses in the WiTEC environment were 54.2% and 43.8%, respectively. These percentages were significantly higher than those for multiple responses given in lectures in the non-WiTEC environment.

More students responded to the teacher's questions with WiTEC. In general, the results show that the students participated in the learning activities more actively with WiTEC than in the environment without WiTEC. The lecture videos demonstrate that most of students could not respond to the teacher when they were only asked questions orally. The students knew how to answer the teacher's questions, but did not know what the teacher was asking. As the teacher wrote down the questions, students were able to speak the answers one after another. In addition, the teacher asked students fewer questions in the lectures with WiTEC.

Table 3
Students' Reactions to the Teacher's Questions During the Polynomial Lectures

Reaction to questions	Lecture 1 questions (non-WiTEC)	Lecture 2 questions (with WiTEC)	Lecture 3 questions (with WiTEC)	Lecture 4 questions (non-WiTEC)
None	14 (43.8%)	2 (8.3%)	1 (6.3%)	9 (42.9%)
One response	10 (31.3%)	5 (20.8%)	5 (31.3%)	5 (23.8%)
Multiple responses	6 (18.8%)	13 (54.2%)	7 (43.8%)	5 (23.8%)
All respond	2 (6.3%)	4 (16.7%)	3 (18.8%)	2 (9.5%)
Total	32	24	16	21

Notes. WiTEC, wireless technology–enhanced classroom. Not all columns total exactly 100.0% because of rounding.

Interviews with the teacher confirmed that the teacher asked new questions when students did not respond to her questions. The styli of the Tablet PCs in the WiTEC environment functionally assisted oral teaching by making the questions understandable to the students. The teacher asked fewer questions with WiTEC since students actively responded to the teacher's questions. Thus, the WiTEC environment enhanced the efficiency of teacher-student interaction and encouraged students participation in teaching and learning activities.

The lecture videos indicated a high rate of response to the teacher's queries in the WiTEC environment (Table 4). When only a conventional whiteboard was used as a shared focus for the lecturing, students had to guess where on the whiteboard the teacher was explaining according to where the teacher was standing and where she was pointing. However, the WiTEC environment enabled the teacher to divide the teaching material into sections, each emphasizing only a unit or example. Dividing the material into small sections reduced students' cognition load. In addition, the styli of the Tablet PCs enabled the teacher to draw students' attention to a specific area in the learning materials. The environment allowed the students to concentrate on a small section of the content and avoid being disturbed by other information. Therefore, the WiTEC environment increased students' awareness of teaching progress and advanced their understanding of the lecture.

The lecture videos also demonstrate that only 3 students appeared distracted during the two lectures with the WiTEC environment, as opposed to 13 during the two non-WiTEC lectures. Specifically, 7 students were distracted during the first, non-WiTEC, lecture; 1 during the second, WiTEC, lecture; 2 during the third, WiTEC, lecture; and 6 during the last, non-WiTEC lecture. Distraction was thus significantly reduced in the WiTEC environment. The response rates shown in Tables 3 and 4 (for status response and question response frequency) can explain the improvement, since the WiTEC environment facilitated effective teacher-student interaction and engaged students in the teaching activities. Therefore, the WiTEC environment enhanced student awareness of learning progress, and decreased opportunities for students to be distracted.

Table 4
Students' Frequency of Responses to Status Questions During Polynomial Lectures

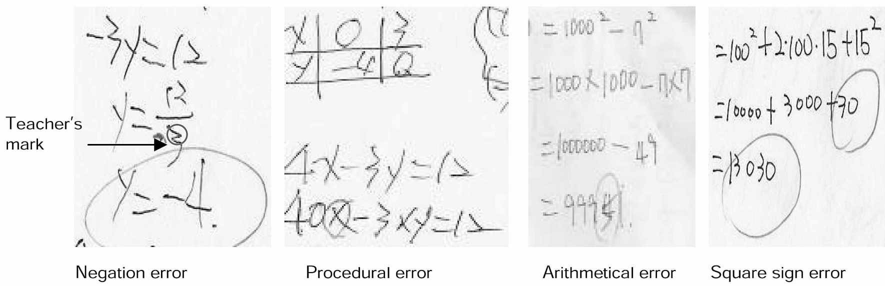
	Lecture 1 (non-WiTEC)	Lecture 2 (with WiTEC)	Lecture 3 (with WiTEC)	Lecture 4 (non-WiTEC)
Teacher's status queries	10	12	10	11
Student responses	2	9	6	3

Student Course Work Analysis

After introducing and developing teaching activities, the teacher assigned a problem as course work and asked students to submit their solutions to solve the problem. The course work was analyzed to identify the mistakes made by students and examine how the scaffolding tools facilitated learning. Student course work was recorded in Tablet PCs when the WiTEC environment was used or on paper work sheets when WiTEC was not used. Each student had to solve eight problems in polynomials and eight in geometry. Therefore, the analysis of course work involved 112 work sheets. The analysis of the student course work on geometry and polynomials revealed four types of errors (see Figure 8):

- *Negation error*: Some students did not correctly deal with the minus sign and distinguish between negation and subtraction.
- *Procedural error*: Students did not apply correct procedures to solve a problem. For example, Figure 8 shows the case of a student not using a correct procedure to solve the equation $4x - 3y = 12$ when $x = 0$.
- *Arithmetical error*: Students incorrectly calculated an expression.
- *Square sign error*: Students did not distinguish between squaring and doubling.

Figure 8
Error Types Found in Student Course Work Related to Polynomials and Geometry



From the non-WiTEC environment to the WiTEC environment, the incidence of the negation error in geometry course work decreased 76.9%, from 13 occurrences to 3; procedural error decreased 92.3%, from 13 occurrences to 1; arithmetical error decreased 62.5%, from 8 occurrences to 3. In the course work on polynomials, when the hard of hearing students did course work using Tablet PCs and scaffold tools, square sign error decreased 80%, from 5 occurrences to 1; procedural errors decreased 72.7%, from 11 to 3; arithmetical errors decreased 62.5%, from 8 occurrences to 3. These data suggest that using scaffold tools at Tablet PCs in solving problems significantly reduced the number of errors made by students. The reduction in errors resulted from the teacher providing correct steps and giving example demonstrations to the students. All students could concentrate on the current step to a solution when aided by the complementary information. Additionally, the complicated problems were broken down into several steps by scaffold tools, significantly lightening students' cognition load.

The scaffold tools guided students to solve problems sequentially. The design prevented students from making procedural errors on impulse and forced them to take the correct path to solve the assigned problems carefully. Additionally, the demonstrated steps gave students a direction to imitate as they attempted to solve a problem, reducing their carelessness and suggesting detailed solutions to decrease the negation and square sign errors.

Student Questionnaire Feedback

A questionnaire consisting of six 5-point Likert-type scale items was administered to measure student perceptions of the WiTEC environment and software tools. The teacher explained each question to students to ensure that the students were aware of its meaning. The complete questionnaire results concerning the WiTEC and software tools are provided in Table 5.

The questionnaire results reveal that hard of hearing students considered the WiTEC environment and software tools to be helpful for learning. Use of Tablet PCs enabled the students to understand the teaching contents, and the scaffold tools helped them to answer questions. The assessment tool, where the entire process was projected onto the projector as a formative assessment method, helped students easily understand all the processes in obtaining the correct answer. Furthermore, the students learned mathematics in a relaxing way in the WiTEC environment. All of the students stated that the WiTEC environment was acceptable and desirable, and that they hoped to continue using WiTEC to learn mathematics.

Table 5
Student Feedback on WiTEC and Software Tools

Statement	*M*
I understand my teacher's teaching, as we use the Tablet PCs and shared whiteboard.	4.57
I understand the correct answer, as I see the whole assessment process on the Tablet PCs and shared whiteboard.	4.42
The example and steps of the scaffold tools help me to answer questions as I practice math exercises.	4.42
Learning math is easier using the Tablet PC environment.	4.42
I like the method of lecturing with the Tablet PC in class.	4.85
I hope to continue using the computer in my math class.	4.42

Notes. WiTEC, wireless technology–enhanced classroom. A 1-5 Likert-type scale was used, with 5 indicating the strongest agreement with the statement.

Conclusion

The present study presented an application of wireless technology to improve the teaching and learning experience with deaf and hard of hearing students. A wireless technology–enhanced classroom environment was implemented to examine its effect on teacher and student behavior during learning and teaching in classrooms. A wireless network using Tablet PCs as personal devices is proposed to improve communication between students and teachers. The highly interactive communication between the Tablet PCs of the teachers and students enabled the simultane-

ous exchange of course work for dynamic assessment.

The computation power of Tablet PCs allowed scaffolds to be prepared during lecturing to reduce students' cognitive load. With the WiTEC environment, the Tablet PC stylus enabled students to practice exercises as if on paper while having the electronic scaffolds from computers. The Tablet PCs and scaffolding tools significantly enhanced student achievement in course work. Additionally, the combination of Tablet PCs, styli, and the wireless network contributed to convenience and more clearly understood lecturing. The student-teacher interaction in the WiTEC environment helped students to understand the lecture content and decreased distraction. Hence, the WiTEC environment reduced communicative difficulty and augmented the interaction between the teacher and the hard of hearing students, thus increasing these students' participation in learning activities.

Note

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