Chang, B., Wang, H.-Y., Peng, T.-Y., & Hsu, Y.-S. (2010). Development and Evaluation of a City-Wide Wireless Weather Sensor Network. *Educational Technology & Society*, *13* (3), 270–280.

Development and Evaluation of a City-Wide Wireless Weather Sensor Network

Ben Chang[1], Hsue-Yie Wang[2], Tian-Yin Peng[3] and Ying-Shao Hsu[4]
[1]Department of E-Learning Design and Management, National Chiayi University, Taiwan // ben@ncyu.edu.tw
[2]Graduate Institute of Network Learning Technology, National Central University, Taiwan // hsuyie@cl.ncu.edu.tw
[3]Department of Earth Sciences, National Taiwan Normal University, Taiwan // 696440064@ntnu.edu.tw
[4]Graduate Institute of Science Education & Department of Earth Sciences, National Taiwan Normal University, Taiwan // yshsu@ntnu.edu.tw

ABSTRACT

This project analyzed the effectiveness of a city-wide wireless weather sensor network, the Taipei Weather Science Learning Network (TWIN), in facilitating elementary and junior high students' study of weather science. The network, composed of sixty school-based weather sensor nodes and a centralized weather data archive server, provides students with current weather data at specific locations in the city. In 2006-2008, annual weather science tournaments were held to encourage students to use this resource, and up to now 171 registered teams, including 447 grade 4-9 students and 220 teachers, have participated in competitions. This study of the tournament data makes clear the over-all efficacy and usability of the network. An analysis of the students' weather science ability demonstrated that they could perform well in the questioning phase, the planning phase and the analyzing phase but not as well in the interpreting phase of their specific weather-science inquires.

Keywords

Wireless weather sensor network, Weather science learning, Taipei weather science learning network

Introduction

Generally, scientific inquiry means the process by which scientists study, analyze and try to explain natural phenomena. In order to develop student inquiry competences, teachers need to provide opportunities for them to experience how scientists actually do science. Scientific inquiry competences include observation, questioning, generating hypotheses, conducting experiments or investigations, analyzing and explaining data, proposing answers and so on (AAAS, 1993; NRC, 1996; NRC, 2000; White & Fredriksen, 1998; Sandoval, 2001). The meaning of scientific inquiry changes with time. In the 1960s, inquiry referred to scientific learning through laboratory work and as a reasoning process for seeking answers to questions. In 1995, the National Science Council's National Science Education Standards focused on inquiry. According to these Standards, inquiry can have two meanings: "First, it refers to the abilities students should develop to be able to design and conduct a scientific investigation and to the understandings they should gain about the nature of scientific inquiry. Second, it refers to the teaching and learning strategies that enable scientific concepts to be mastered through investigations (CSMEE & NRC, 2000, p. XV)."

Instead of memorizing factual knowledge, repeating answers, and listening to lectures, higher-order thinking skills such as inquiring, exploring, proposing questions and independent problem solving are important for students who must face a world filled with new challenges. Science learning is essentially a question-driven, open-ended process, and students must have some personal experience with scientific inquiry to understand the fundamental aspects of science (Linn, Songer & Eylon, 1996). Science learning activities help students develop cognitive abilities (e.g., critical thinking and reasoning) as well as scientific knowledge (Linn, 2003). Many studies have proposed learning models to explain the student inquiry process and to provide a basis for curriculum design and professional development of teachers in order to facilitate science learning. Krajicik *et al.* (1998) proposed an investigation web to facilitate student inquiry and problem solving. White (1993) used an inquiry cycle to interpret the process of students' scientific inquiry. This technology helps students to collect and analyze data, and share their ideas with others. In some cases, technology can be used as a tool for knowledge construction and critical thinking (White, 1993; Jonassen, Peck & Wilson, 1999). Information and communications technology, then, can be used not only to store and manipulate huge amounts of information but also to encourage students' interaction with information in a variety of formats, help them perform complex computations, support their communication and respond rapidly to individual users (Blumenfeld *et al*., 1991).

Mobile and wireless technology can provide substantial support in science learning. One of the novel mobile and wireless technologies is the wireless sensor network technology, which can be applied by embedding sensors in the everyday living environment and connecting these sensors to a network. A wireless sensor network consists of spatially distributed autonomous devices that use sensors to cooperatively monitor physical or environmental conditions (Akyildiz, Su, Sankarasubramaniam & Cayirci, 2002). In the present study, a city-wide wireless weather sensor network, the Taipei Weather Science Network (TWIN) which physically covers the whole of Taipei City, was built to automatically log the day-to-day weather conditions in Taipei City (Chang, Wang & Lin, 2009). Sixty schools have been involved in TWIN. As a novel learning platform, TWIN is an open Taipei City weather data archive providing students with a data-rich environment to explore, investigate and study. Hence it can facilitate weather science learning by making readily available real-time, past or historical weather data in any part of the city.

City-Wide Wireless Weather Sensor Network

The geography of Taipei City consists of a basin surrounded by mountains and several rivers. The highest mountain in the city is 1,120 meters. The unique geography of Taipei City makes for an extraordinary climate. In order to collect the Taipei City weather conditions and then applied them to students' weather science learning, a city-wide wireless weather sensor network, TWIN, was established. TWIN provides a distributed wireless weather sensor network throughout Taipei and promotes weather science learning activities for students. The TWIN project was initiated in December, 2003. The Taipei City government first set up thirty wireless weather sensor nodes in thirty schools, and then added thirty more nodes in other schools in May, 2004. Taipei City is divided into twelve districts, each of which has a unique geographical landscape. Therefore, the locations of the weather sensor nodes in the sixty schools were carefully selected. The deployment rule was that each district should be allocated at least three wireless weather sensor nodes. Some special geographical locations, such as mountain areas or river regions, were allocated more nodes in order to gather more detailed weather data. The sixty weather sensor nodes were connected by a centralized archive server. The weather data from the area around the weather sensor node were collected every five minutes and wirelessly transferred to the TWIN server. Figure 1 shows the distributed architecture of TWIN.

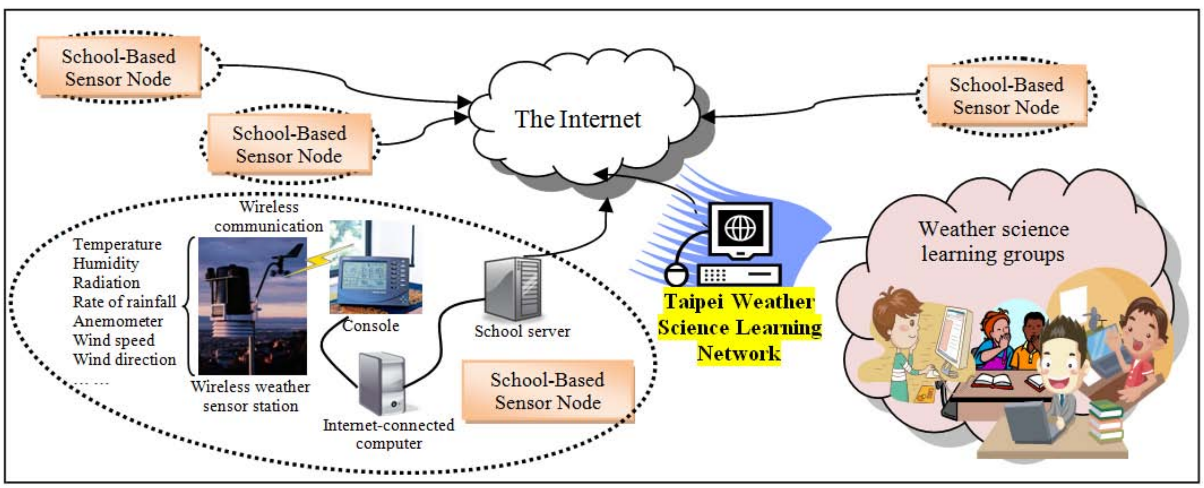

Figure 1. Taipei weather science learning network architecture

The TWIN website is open to the public (Figure 2); users who are interested in using the data for Taipei City weather science learning can freely access the database. The website provides not only the current weather status at a particular weather sensor node, but also the past data for all nodes and for elapsed-time periods of five minutes, an hour, a week, or a month. Additionally, desired weather data can be downloaded in Excel file format for further processing.

School-based weather sensor node

TWIN comprises sixty school-based weather sensor nodes distributed throughout Taipei City. A school-based weather sensor node includes a wireless weather sensor station, a data receiving console connected to an Internet-connected computer, and a school server. The weather data in the school server is obtained from the weather sensor station installed on the campus. The weather sensor station used on TWIN is a commercial component named Vantage Pro. The device can detect temperature, humidity, barometric pressure, UV radiation, rainfall rate, wind direction, wind speed and other data. The weather sensor devices are solar powered, and each is equipped with an accumulator and a wireless module that enables the station to work twenty-four hours a day, seven days a week, independently. The weather data measured by the sensor station is transmitted automatically and wirelessly to the console to generate such data as dew point, wind chill temperature, temperature-humidity-wind (THW) index, and heat index. The weather school server displays the current weather status in both numerical and graphical type. As Figure 3 shows, this data provides essential weather data such as highest and lowest temperature of the day, month, and year as well as a 24-hour temperature change curve, etc. By studying the data, the students will become more aware of their living environment.

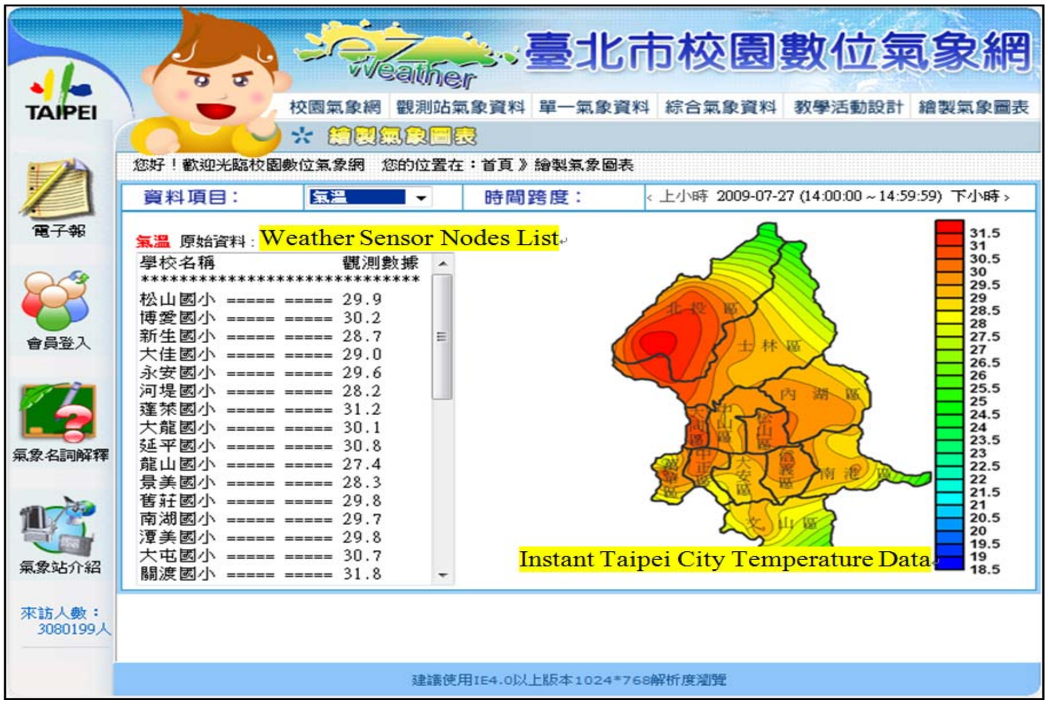

Figure 2. Instant weather data on TWIN

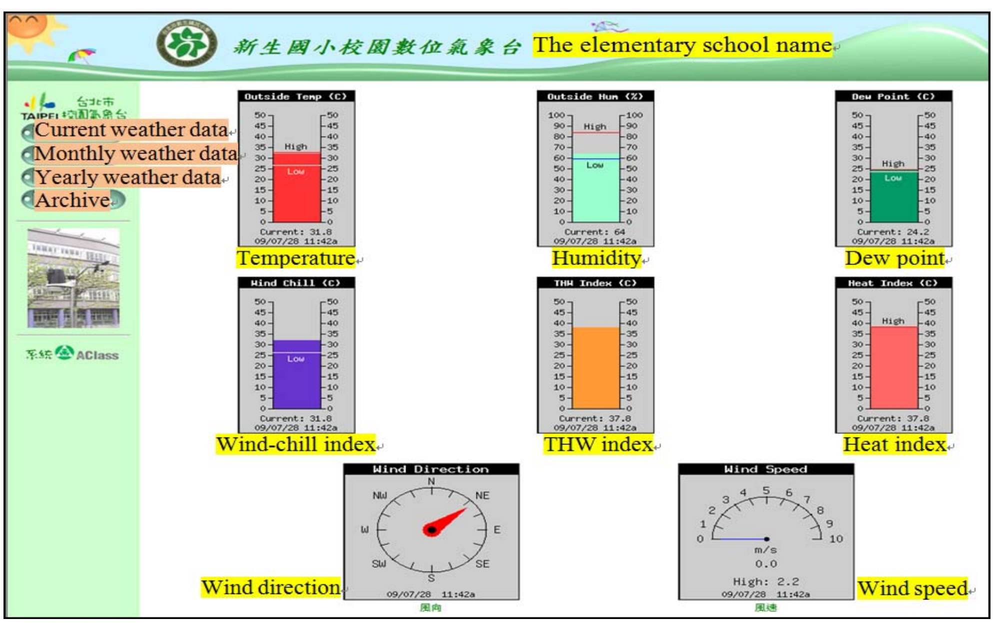

Figure 3. Xin Sheng elementary school-based weather sensor node

These school-based weather sensor nodes are connected by the TWIN server, and all of Taipei City's weather data will be automatically transferred from all the school-based nodes to the TWIN server, or retrieved by the TWIN server if it did not receive the uploaded data. The bidirectional data transmission mechanism ensures that current weather data is securely saved on the TWIN server.

The benefits of practicing weather science learning on a city-wide wireless sensor network

As an ad hoc wireless network, TWIN makes Taipei students' study of their own weather more convenient and more effective. The advantages of using TWIN in the learning of weather science are the following:

- Students are provided with actual and real-time data: The TWIN provides actual and real-time weather data for Taipei City where the students live. These data are logged and analyzed automatically. The students who participated in the task-oriented TWIN project spent less time in collecting raw data but more time in analyzing and applying data.
- Students practice weather science learning in a geographically unrestricted exploratory environment: TWIN detects the current weather status at various points around the city and provides this data to the public. The students can access and explore this data easily through the Internet.
- This activity is student-oriented: TWIN is a data-rich weather platform. The role of the TWIN teacher is that of a consultant rather than an instructor. The students acquire the weather science knowledge by themselves. They must decide which topic or problem to explore and then develop strategies for studying the topic or solving the problem they have proposed.
- A digital archive is created: The TWIN is an automatic operating system. Since 2004, this system has collected and archived Taipei City weather data which is available to all teachers and students.

Four-Phase Weather Science Learning Activity Design

TWIN provides a large Taipei City weather database and a platform for students to explore. However, providing an exploratory environment is only the first step. To provide a complete weather science learning activity for students, a four-phase learning activity was designed. The students who are interested in the TWIN weather science learning program are asked to form a team and explore and analyze the data collaboratively.

Questioning phase

A questioning phase preceded the weather science activity so teachers and students could first select the weather science problem they wanted to inquire. In this stage, the students were asked to participate in surveys and make certain assumptions. The goal of this phase was to encourage students to identify a problem that they were interested in solving. Initially, the students knew very little about TWIN and the problem they wanted to investigate. To help them determine their own problem they discussed their own experiences of Taipei weather. Four anchored topics were provided to trigger the student discussions:

The four anchored topics were the following:
Anchored topic 1: Choose a physical area in Taipei City and study its humidity.
Anchored topic 2: Choose two different topographies in Taipei City and study the humidity data.
Anchored topic 3: Study the hottest or coldest area in Taipei City.
Anchored topic 4: Study the area of Taipei City that has the highest rainfall.
Others: Select your own topic if you are not interested in any of the above topics.

These four anchored topics were then used to help students clarify their ideas and the weather science learning problems that were most interesting to them. The team members were encouraged to engage in reading, discussion and brainstorming at this stage. Worksheet I in Table 1 was used to guide students in formulating a weather science problem. Each team was requested to complete it in one week.

Planning phase

After selecting its own weather science problem in the first stage, each team was asked to generate a plan for solving their problem in the second stage. Team members were encouraged to have group discussions of the problem and to make initial assumptions. They were asked to do preliminary research using the TWIN database to help generate their hypothesis. This stage required students to decide the data items, the quantity of data, and the types of statistical graphs needed for solving their problem. Each team then divided the problem solving tasks into subtasks and dispatched them to each member. Worksheet II listed in Table 1 was used to guide the students in designing a scientific investigation, answering a question or testing a hypothesis. Each team was asked to complete the task within one week.

Analyzing phase

In this phase, the students kept their assumptions and hypotheses in mind and set out to find their answers. They were required to find evidence from the TWIN data to support their hypotheses. The students thus needed to explore the data retrieved from TWIN and filter out only the data directly relevant to their inquiry problem. After the first and second phases, the students began to have a clearer idea about how to use TWIN and the question they were interested in answering. Following these two phases, the third phase encouraged the students to find data, evidence, and statistical results from TWIN to support the assumptions and hypotheses they had proposed in the second phase. The students were required to work in teams to analyze the TWIN data and to use tools such as Excel to calculate the weather data and create graphics to display this data. Worksheet III listed in Table 1 was used to guide students in collecting, organizing, and displaying the data they used to support their analysis. All teams were required to complete and upload their completed worksheets within one week. Of course, the students were allowed to refer back to the previous phase if they found some cues that did not support their assumptions or hypotheses.

Interpreting phase

In the final phase, the students had completed their weather science inquiry process and were asked to verify their results. They had to demonstrate their findings in terms of concrete values, graphs, and tables. Some tasks, such as data analysis, group discussion, and writing reports, were performed during this phase. Each team attempted to reconcile its findings with its original hypothesis and then draw some conclusions and engage in discussions at this stage. Worksheet IV listed in Table 1 was used to guide the students in summarizing and analyzing data, interpreting results, and selecting reasonable and accurate interpretations and implications. The students were required to complete worksheet IV in one week.

Table 1. Four-phase inquiry worksheets

Worksheet I: Questioning phase Finding inquiry topic. Related questions following the topic. The final inquiry problem. Why was this problem selected as the inquiry problem? Possible solutions to the problem. Difficulties encountered in this phase.	Worksheet II: Planning phase Revise the previous worksheet if needed, and list the reasons. List the data items to be collected and explain the relationships between and among the data and the proposed items. Give the elapsed time for the most recently logged data and reasons for logging it. List the data sources. How can these data sources be used? Difficulties encountered in this phase.
Worksheet III: Analyzing phase Revise the previous worksheet if needed, and list the reasons. During the inquiry process, how much data was logged in terms of total quantity. Convert the logged data to graphics. List the patterns described by the logged data. Difficulties encountered in this phase.	Worksheet IV: Interpreting phase Revise the previous worksheet if needed, and list the reasons. According to the data and graphics provided, can the questions be answered? According to the data, graphics, and proposed questions, what evidence is available? Do the findings support the assumptions listed in the worksheet I? Why? Do these findings support the questions listed in worksheet I? Why? Difficulties encountered in this phase.

Four-phase weather science learning worksheets

As mentioned above, the four-phase worksheets shown in Table 1 were designed to facilitate student weather science learning activities. These worksheets were presented in question-and-answer format. The questions were intended to trigger interaction among team members and to provide a guideline for accomplishing their inquiry tasks. The worksheets were given once weekly. Before starting each worksheet, the teams were requested to upload the completed previous worksheet.

Practice and results

The TWIN platform was established in 2004 as an open platform for the public. In 2006, after the establishment of the infrastructure, a series of annual weather science learning tournaments was held, organized by Taipei City volunteer elementary school teachers. The students registered for the tournaments through the TWIN voluntarily, and completed the four worksheets using outside-class time. Each team was composed of three to five students, and each was assigned one or two teachers as coaches. A coach could consult with more than one team. Each tournament was a five-week event. Following the four-phase weather science learning worksheets mentioned in Table 1, the team members were asked to complete the worksheets for each inquiry phase once a week. Oral presentations were given in the last week. After completing the last worksheet, all worksheets were reviewed by ten elementary and junior high school science teachers, who selected thirty to forty teams to attend a workshop. All the selected teams' worksheets were then reviewed by three experts: one computer science professor, one natural science education professor, and one weather scientist. Each selected team had to prepare a PowerPoint file based on their findings for the workshop. Each group was asked to deliver presentations and answer three to five questions proposed by the experts. So far, 171 teams including 447 grade 4-9 students and 220 coaches have participated in these events. The number of teams in 2006, 2007 and 2008 were twenty-six, fifty-four, and ninety-one. In 2006, 30 coaches and 67 students participated in the tournament; in 2007, 71 coaches and 144 students participated; in 2008, the number of coaches and students soared to 119 and 236, respectively. While the number of participants increased dramatically each year, some teams failed during the tournaments. In 2006, three teams quit the tournament during a 5-week period; in 2007, fourteen teams quit and in 2008, twenty-one teams quit. See Table 2 for a summary.

Table 2. Basic data for the 2006-2008 weather science IBL tournament series

	2006	2007	2008
Registered Teams (coaches, students)	26 (30, 67)	54 (71, 144)	91(119, 236)
Valid Teams (WSN, non-WSN)	23(15,8)	40(25,15)	70(35,35)
Invalid Teams (WSN, non-WSN)	3(1,2)	14(7,7)	21(10,11)

WSN: their school has a weather sensor node

Usability study of the TWIN platform

The infrastructure of the TWIN is huge, and covers the sixty schools in Taipei City. One question was therefore whether the TWIN could be used by the students even if their school did not have a weather sensor node. For the purposes of statistical study, the registered teams were catalogued as WSN (having a weather sensor node) and non-WSN. In 2006, twenty-six teams (including valid teams and invalid teams) registered to participate in the tournament. Among them, sixteen were WSN and ten were non-WSN. Of the fifty-four teams that attended the event in 2007, thirty-two were WSN and twenty-two were non-WSN. In 2008, the number of registered teams soared to ninety-one. Among them, forty-five were WSN and forty-six were non-WSN. The number of non-WSN exceeded the number of WSN teams in 2008.

Furthermore, in 2006, among the sixteen WSN teams, fifteen completed the inquiry activity and seven won awards. Of the ten non-WSN teams that year, only eight finished the five-week inquiry activity and only three won awards. In 2007, thirty-two teams were WSN: twenty-five finished the inquiry process and seven won awards. In the same year, twenty-two teams were non-WSN: fifteen completed the process and only four won awards. Before 2008, then, the WSN teams generally outperformed the non-WSN teams, but 2008 was a turning point. In that year, forty-five teams were WSN: thirty-five completed the process and seven won awards. In the same year, forty-six teams were non-WSN: thirty-five completed the inquiry process and seven won the award, the same as the number of WSN teams winning it.

Each year, all teams were reviewed by a committee, and teams with superior results were selected and given awards. According to the statistics listed in Figure 4, the fifth-grade students are the greatest number of awards over the three-year period, meaning that over-all they demonstrated the greatest capability for weather science learning on the TWIN platform. As for the poor showing of the ninth-grade students, it must be borne in mind that in Taiwan ninth graders are under great pressure due to senior high school entrance examinations, and they are less likely to spend time on such activities.

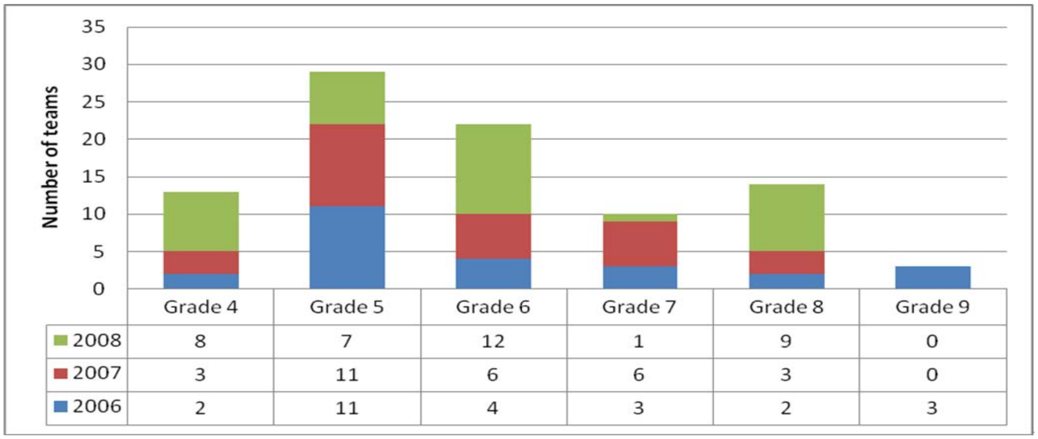

Figure 4. Awarded teams by grade level and number of students in 2006-2008

Analysis of student weather science learning abilities

To examine students' performance when they used the TWIN platform from 2006 to 2008, a rubric was proposed to score student inquiry abilities. This rubric was modified from the Official Scientific Inquiry Scoring Guide-Grades 6, 7, and 8 (Official of Teaching and Learning, n.d.) of the Oregon Department of Education, based on the transcripts of student worksheets, and then validated by the three experts (one science educator and two high school teachers currently in Ph. D. programs in science education). This rubric included four kinds or phases of inquiry ability: questioning, planning, analyzing, and interpreting. Each phase was coded in terms of three dimensions: application of scientific knowledge, communication, and the nature of scientific inquiry. Therefore, each phase included three constructs. The researchers gave each construct a scale of 0 to 3 points. Table 3 presents the rubric.

Questioning. The researchers coded the transcripts in Worksheet I in three dimensions. The *application of concepts* construct was placed in the application of scientific knowledge dimension, the *interpretation of topics* construct in the communication dimension, and the *inference of topics* construct in the nature of scientific inquiry dimension. The researchers scored *application of concepts* from 0 to 3 points according to how clearly the applied concepts were described and their relevance to the question. They scored *interpretation of topics* from 0 to 3 points according to the relevance of the question to a given topic and how clearly the students described the factors in the question. Inference of topics was scored from 0 to 3 points according to how correctly the students described the scientific meaning or relevance of the possible answers to the question.

Planning. The researchers coded the transcripts in Worksheet II in three dimensions. The *manipulation of investigation* construct was in the application of scientific knowledge dimension, the *completeness of proposal* construct was in the communication dimension, and the *appropriateness of proposal* construct was in the nature of scientific inquiry dimension. The researchers scored manipulation of investigation from 0 to 3 points, according to how clearly students listed the data items they wanted to collect and elaborated the relationships among or between the data. Completeness of proposal was scored from 0 to 3 points according to how completely they organized and structured the investigation proposal and detailed procedures; appropriateness of proposal was scored from 0 to 3 points according to how clearly students answered questions using sufficient data and reasoned using appropriate diagrams.

Analyzing. The researchers coded the transcripts in Worksheet III in three dimensions. The *processing of data* construct was in the application of scientific knowledge dimension, the *presentation of data* construct was in the communication dimension, and the *transformation of data* construct was in the nature of scientific inquiry dimension. For the processing of data, the researchers gave a score of from 0 to 3 points according to how properly students answered questions based on measurements or observations, and on how errors could be reduced. For data presentation, the researchers gave the students scores from 0 to 3 points according to how appropriately they converted the logged data into graphics or/and tables. For transformation of data, the researchers scored the students from 0 to 3 according to how clearly they transformed the data to support results.

Interpreting. The researchers coded the transcripts in Worksheet IV in three dimensions. The *explanation of data* construct was in the application of scientific knowledge dimension; the *making a conclusion* construct was in the communication dimension; and the *examination and evaluation* construct was in the nature of scientific inquiry dimension. Explanation of data was scored from 0 to 3 points according to how clearly students explained the relationships between and among variables or/and trends based on the data. Making conclusions was scored from 0 to 3 points according to how clearly students presented results and how correctly they drew conclusions. Examination and evaluation was scored from 0 to 3 points according to how clearly students explained important limitations and sources of error and pointed out possible directions for improvement.

Table 3. Four phases and three dimensions of scientific inquiry

Phase	Application of Scientific Knowledge (a)	Communication (c)	Nature of Scientific Inquiry (n)
Questioning	Q-a: Application of concepts	Q-c: Interpretation of topics	Q-n: Inference of topics
Planning	P-a: Manipulation of investigation	P-c: Completeness of proposal	P-n: Appropriateness of proposal
Analyzing	A-a: Processing of data	A-c: Presentation of data	A-n: Transformation of data
Interpreting	I-a: Explanation of data	I-c: Making conclusions	I-n: Examination and evaluation

The subjects for analysis of student inquiry abilities were those students who had participated in annual weather science learning tournaments from 2006 to 2008. They filled out and submitted four worksheets (worksheets I, II, II and IV listed in Table 1), in teams, once a week. After excluding invalid subjects, twenty-three, forty and seventy teams participated in 2006, 2007, and 2008 respectively (see Table 2). Two raters randomly chose five teams each year (fifteen teams in total) for coding based on the rubric mentioned above, and the inter-rater reliability reached 0.88.

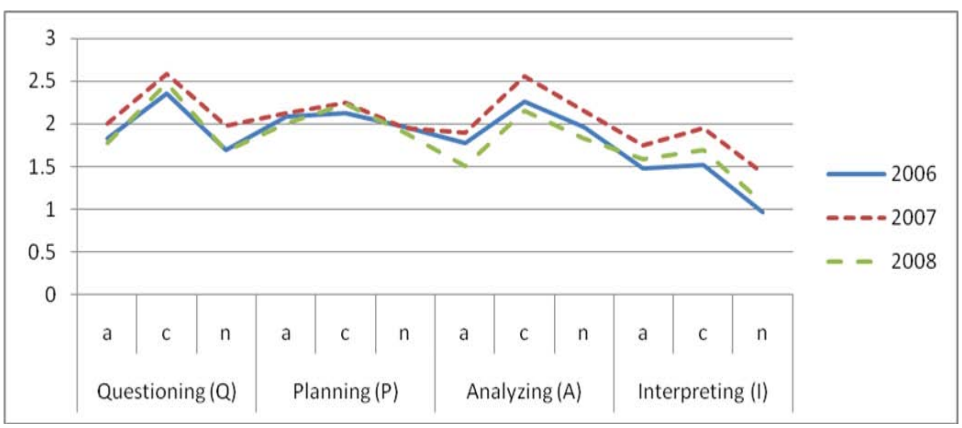

Figure 5. Descriptive analysis of student inquiry abilities from 2006 to 2008
a: Application of Scientific Knowledge; c: Communication; n: Nature of Scientific Inquiry

The purpose of the coding scheme was to define the important aspects of a task and to provide guidance for assessing student inquiry abilities. After the student answers in the four worksheets were coded based on the rubric shown in Table 3, the analytical results showed that the student performances in most of the constructs improved slightly from 2006 to 2008, presumably because the students could review worksheets from the previous year and learn from them, and also because the teachers had become more familiar with TWIN and were better at using it with the students. However, the students continued to perform poorly in the fourth phase, the interpreting phase, including explanation of data, making conclusions, and examination and evaluation, over the three-year period (see Figure 5). This outcome suggests that students need support and guidelines when interpreting tables and figures they generated, in making conclusions, and in evaluating results.

Detailed analysis of the answers to the worksheets indicated that the students performed well in several constructs. For instance, they could manipulate several variables and understand the relationships among them under controlled conditions. They also demonstrated organization and planning skills. The answers below from two groups (G2007-4-9 and G2007-4-3) that participated in 2007 showed that they planned to collect the data regarding the variables related to humidity based on their understanding of the relationships between these variables.

> We prepared to collect data on precipitation, station locations, humidity and terrain. We thought that temperature could affect humidity, and humidity could affect precipitation. We wondered whether the different terrain would affect precipitation (G2007-4-9).

> In twelve chosen districts, we randomly selected two stations in each area, a total of twenty-four stations. The hourly data from 2004 to 2006 were used for data analysis. In July, there often were thunderstorms in the afternoons. This was caused by specific conditions regarding air pressure, wind direction, humidity, and terrain (G2007-4-3).

In the past three years, most of the students could convert data into appropriate diagrams in order to present the results clearly. The following is an example from a group in 2008 (G2008-1-3, see Table 4).

Table 4. A summary of averages for three months (March, April, and May) (G2008-1-3)

	Hua-Jiang Elementary school	Tai-Ping Elementary school	Yan-Ping Elementary school	Sho-Zhi Elementary school	Zhou-Mei Elementary school	Kuan-Tu Elementary school	Average
Average temperature	17.26ºC	17.40ºC	17.65ºC	17.55 ºC	17.27ºC	17.7ºC	17.47ºC
Average pressure	1017.82hPa	1017.82hPa	1015.60hPa	1017.59hPa	1016.92hPa	1017.25hPa	1017.17hPa
Average rainfall	3.61mm	3.61mm	3.07mm	3.69mm	3.21mm	2.72mm	3.32mm
Average *humidity*	71.31%	71.51%	72.40%	72.39%	73.37%	77.94%	73.15%
Humidity place	6	5	4	3	2	1	

Overall, the findings indicated that the students performed well in scientific inquiry with the TWIN platform except for the interpreting phase. Regarding the latter, most students could not explain data based on theories and often drew conclusions unrelated to their questions. One team (G2007-5-8) in 2007 interpreted their results based on their life experiences, and another team (G2006-2-8) in 2006 could not draw a meaningful conclusion because they did not control other relevant variables.

> It was quite suitable to play or to go for a walk in the countryside at the beginning of July and at the end of August, because the ultraviolet index was quite low (G2007-5-8).

> There was no certain pattern in humidity associated with terrain. Humidity was higher in mountainous areas sometimes and humidity was higher in a plain sometimes (G2006-2-8).

Discussion and Conclusions

Participation in science learning can provide students the opportunity to develop general inquiry abilities, to acquire specific investigation skills, and to understand science concepts and principles (Edelson, Gordin & Pea, 1999).

Technology, especially mobile and wireless, can be applied in science learning. In 2004, a city-wide wireless weather sensor network named TWIN (Taipei Weather Science Learning Network) composed of sixty weather sensor nodes was deployed in sixty Taipei City elementary schools. TWIN provides updated weather data for various points in Taipei City every five minutes. This data is saved at a central server and is open to the public. TWIN proved to be very useful in giving elementary and junior high school students actual and instant weather data, allowing them to explore this data in a geographically free and open environment, providing them with an effective, task-oriented learning activity, and enabling them to prepare a digital archive. A series of annual weather science learning tournaments was held in 2006-2008 to encourage the teachers and students to use the TWIN resources. Thus far 171 teams, including 220 teachers and 447 students, have participated in the tournaments. For both teachers and students this was a new experience.

According to the three-year tournament data shown in Table 2 regarding the participation rate, completion rate, and higher-achievement teams, in 2006 the WSN teams performed better than the non-WSN teams. The difference between the WSN and non-WSN students in 2007 was very small, and the WSN students had slightly better results than the non-WSN students. In 2008, the WSN students and non-WSN students performed almost equally. This indicated that all students, even if their school lacks a sensor node, can perform well. The data also indicates that most of the teams can complete the weather science learning activity. The overall data for the three-year tournaments shows that the TWIN platform has an at least acceptable degree of usability and effectiveness.

The analysis of data regarding student weather science abilities, as described in the analysis of the student weather science learning abilities section, indicated that the students in general could perform well in the questioning phase, planning phase, and analyzing phase, but not in the interpreting phase. Another interesting statistic concerns the number of teams that quit the tournaments. In 2006, three teams gave up. Among them, one team gave up in the planning phase, one team in the analyzing phase, and one team in the interpreting phase. In 2007 fourteen teams gave up, two in the questioning phase, one in the planning phase, four in the analyzing phase and seven in the interpreting phase. In 2008, the number of teams leaving before the end of the tournament soared to twenty-one: six gave up in the questioning phase, one in the planning phase, five in the analyzing phase and nine in the interpreting phase. The interpreting phase score is lower than that for any of the other three phases, and the greatest number of teams also quit during the interpreting phase. These data suggest that interpreting the findings was challenging for the students. While it was found that students' weather science ability was generally improved during the questioning, planning and analyzing phases, interpretation is a very important skill as it involves giving the data meaning. Clearly there needs to be more emphasis on helping weather science students to learn how to interpret data. It is therefore suggested that coaches and teachers need to attend workshops which can help them learn strategies for facilitating students' interpretive skill.

The preliminary data for the tournaments does show the positive effects of using the TWIN platform in weather science learning. However, further studies are needed to analyze the process of interpretation, and more generally of meaning-making in the context of student group interaction. In addition, another contest event that on the theme of weather forecast will be took placed in the near future to investigate whether it can deepen students' abilities on data analyzing and interpretation, widen their knowledge coverage and viewpoints of weather science, as well as their interests on meteorology and climatology learning.

Acknowledgment

The authors would like to thank the Taipei City government for financially supporting the TWIN infrastructure and providing logistical support, and the TWIN volunteer team for their efforts.

References

AAAS (1993). *Benchmarks for science literacy*, New York, NY: Oxford University Press.

Akyildiz, I., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). A survey on sensor networks. *IEEE Communications Magazine*, August, 102-114.

Blumenfeld, P. C., Soloway, E., Marx, R., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*, 369-398.

Chang, B., Wang, H. Y., & Lin, Y. S. (2009). Enhancement of mobile learning using wireless sensor network. *IEEE Learning Technology Newsletter, 11* (1&2), 22-25.

CSMEE & NRC (2000). *Inquiry and the national science education standards: A guide for teaching and learning*, Washington, DC: National Academy Press.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *The Journal of the Learning Sciences*, *8*(3&4), 391-450.

Jonassen, D. H., Peck, K. L., & Wilson, B. G. (1999). *Learning with technology: A constructivist perspective*, New York: Prentice Hall.

Krajcik, J., Blumenfeld, P. C., Marx, R. W., Bass, K. M., Fredericks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *The Journal of the Learning Sciences, 7* (3-4), 313-350.

Linn, M. C. (2003). Technology and science education: Starting points, research programs, and trends. *International Journal of Science Education, 25* (6), 727-758.

Linn, M. C., Songer, N. B., & Eylon, B. S. (1996). Shifts and convergences in science learning and instruction. In Calfee, R. & Berliner, D. (Eds.), *Handbook of educational psychology* (pp. 438-490), Riverside, NJ: Macmillan.

National Research Council (1996). *National science education standards*, Washington, DC: National Academy Press.

National Research Council (2000). *Inquiry and the national science education standards: A guide for teaching and learning*, Washington, DC: National Academy Press.

Official of Teaching and Learning (n.d.). *2002-2009 official scientific inquiry scoring guide*, Retrieved May 5, 2010, from http://inside.otl.pps.k12.or.us/.docs/pg/400/rid/15123/f/sciinqu_bk3eng.pdf.

Sandoval, W. A. (2001). Students' uses of data as evidence in scientific explanations. *Paper presented at the annual meeting of the American Educational Research Association*, April, Seattle, WA.

White, B. Y. (1993). ThinkerTools: Causal models, conceptual change, and science education. *Cognition and Instruction*, *10* (1), 1-100.

White, B. Y., & Fredriksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all Students. *Cognition and Instruction, 16* (1), 3-118.