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Impact of a Professional Development Program Using Data-Loggers on Science Teachers' Attitudes towards Inquiry-Based Teaching

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This study examined how a professional development program which incorporates the use of electronic data-loggers could impact science teachers' attitudes towards inquiry-based teaching. The participants were 28 science or technology teachers who attended workshops offered in the United States and Japan. The professional development program emphasized (a) guided inquiry activities, (b) participants' own exploration within the range of given tasks, (c) instructors' guidance on the processes of inquiry and technology, and (d) discussions of the ways to bring their inquiry experiences in their classrooms. Data sources included field notes, video recordings, artifacts, and survey responses. Analysis of participants' discourse identified many instances in which the program helped the teachers deepen their understanding of inquiry-based teaching. The findings are presented as three assertions: (a) all the elements incorporated in the program contributed positively to participants' engagement in inquiry, (b) connections between participants' sensory experiences and graphical representations of data led them to have new understanding of the phenomena under the investigation, and (c) there were strong connections between their experiences about inquiry and teaching strategies that they wanted to incorporate in their classrooms. Applications of the findings into the development of more effective professional development programs will be discussed.

In the National Science Education Standards (NSES) (National Research Council [NRC], 1996), the importance of scientific inquiry has been clearly emphasized in K-12 science education. Scientific inquiry is regarded as the heart of science education because inquiry helps students develop deeper understanding of scientific concepts (Bybee, 2000). The effectiveness of inquiry-based teaching for developing students' deeper understanding of scientific concepts has been suggested by various researchers (Anderson, 2002; Krajcik, Blumenfeld, Marx, & Soloway, 2000; Shymansky, Kyle, & Alport, 1983; Von Secker, 2002).

In spite of the emphasis on scientific inquiry in the science education research community, the literature suggests that few inquiry-based lessons are taking place in actual science classrooms (Lotter, 2004; Reiff, 2002; Simmons et al., 1999). The Third International Mathematics and Science Study (TIMSS) 1999 Video Study of science (National Center for Education Statistics [NCES], 2006) showed that out of 88 US 8th-grade science lessons, 66% of science teachers developed science content mainly by student acquisition of facts, definitions, and algorithms and only 17% developed content through inquiry. It appears that the majority of middle-school science teachers are not translating the guidelines for inquiry-based teaching described in the NSES into their own classroom practice.

One of the reasons for the lack of inquiry-based teaching in science classrooms may be ascribed to the limited experience that teachers have had during their own education. Even while studying for undergraduate degrees in science, science teachers in general have little chance to engage in open-ended explorations (NRC, 2000). While teachers who hold master's degrees in science have probably engaged in autonomous inquiries, teachers who have master's degrees in *science education* normally do not experience scientific investigations in their education courses (McDermott & DeWater, 2000). As a consequence, many teachers have not been given opportunities for experiencing authentic scientific inquiry.

A number of programs have been developed to provide in-service and pre-service teachers with authentic scientific inquiry experiences (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2004; NRC, 2000). These programs mainly aim to develop teachers' abilities and understanding of scientific inquiry through such hands-on activities as table-top experiments, field work, and real lab experiences. More recently, the use of technology to enhance teachers' abilities to conduct scientific inquiry has been explored. The technology tools such as probeware, computer simulations, and online communication tools are regarded as effective means to integrate the use of technology in science teacher education courses to support their inquiry activities (Friedrichsen, Dana, Zembal-Saul, Munford, & Tsur, 2001). While each of the technology tools has its own advantages, the present study focuses on the use of probeware and associated methods in teacher education programs.

"Probeware refers to educational applications of probes, interfaces and software used for real-time data acquisition, display, and analysis with a computer or calculator. Probeware is also known as Microcomputer Based Labs or MBL" (Concord Consortium, 2009). An electronic probe is used to collect information about a physical system and the information is converted to a tabular or graphical representation in approximately real time (Friedrichsen, et. al, 2001; Nakhleh, 1994). The effectiveness of the use of probeware in enhancing student inquiry learning has been empirically shown by a number of researchers (Krajick & Starr, 2001; Metcalf & Tinker, 2004; Nicolaou, Nicolaidou, Zacharia, & Constantinou, 2007; Novak & Krajick, 2004; Russell, Lucas, & McRobbie, 2004). It has been claimed that the ability to access data over various time intervals, and the power of probeware to process, analyze, and display data more rapidly than traditional laboratory methods provide students with more time to manipulate variables, test hypothesis, and explore relationships. Russell et al. further suggested that the use of probeware increases opportunities for students to interact with other students by sharing data and discussing the meanings of data.

In spite of the suggested effectiveness of the use of probeware in students' scientific inquiry, little research has been done to investigate its effectiveness in teacher education programs for the purpose of enhancing teachers' inquiry-based teaching. Probeware in teacher education programs has been mainly used to investigate teachers' attitudes toward the use of technology itself (Gado, Ferguson, & van 't Hooft, 2006; Lyublinskaya & Zhou, 2008). Espinoza (2007) investigated how the use of probeware in a professional development program impacted high school teachers on their abilities of conducting inquiry. Espinoza focused his research on the change of teachers' ability for correctly predicting the outcome of an experiment during the course of the program. Espinoza found that the participants' performance on predictions improved as the program unfolded during four sessions. Martin and Greenwood (2007) conducted a study to examine how the use of data-loggers impacted beginning teachers' awareness of the nature of scientific inquiry. Their results indicated that the teachers became more aware of the fact that science involves various aspects that are not normally described in textbooks when they actually experienced generating questions, collecting data, and interpreting the data using data-loggers. Based on the results of the earlier studies, it would be important to focus the research on the processes of teachers' learning inquiry with the use of technology. Furthermore, as Russell et al. (2004) suggested in their study of student learning of scientific inquiry with the use of probeware, the effect of interactions among peers and instructors in the process of learning would be an interesting point to study in teacher education programs.

This study presents a professional development program using electronic data-loggers that is designed to have an impact on teachers' attitudes toward inquiry-based teaching. Based on the results of the earlier work, a professional development program that would positively affects teachers' attitude was created first. The study examined how this professional development program affected teachers' processes of inquiry, and further affected their feelings toward the use of inquiry in teaching. The following research questions guided the present study:

1. How do participants go through processes of scientific inquiry with the use of data-loggers during the course of the professional development program?

2. How does the professional development program used in this research help participants go through the processes of scientific inquiry?

3. How do the instructors' guidance and other social interactions help participants go through the processes of scientific inquiry using data-loggers?

4. How do participants' inquiry experiences with the use of data-loggers relate to their willingness of the use of inquiry-based teaching strategies in their science classroom?

5. How does the professional development program impact participants' attitudes toward the use of inquiry in their classroom?

The term *data-loggers* instead of probeware is used in this study for two reasons: (a) the electronic data-logging device used in the this study was portable with no real-time display capability, and (b) the instructional approach in the present study was different from the typical probeware approach in which users follow fixed instructions for the activities (Nakhleh, 1994; Nicolaou et al., 2007).

The significance of this study is to inform science educators in higher education about how teacher education programs can enhance inquiry-based teaching. By examining how teachers went through the processes of inquiry with the use of data-loggers in detail, this study reveals what are important elements in teacher education programs. This study further provides science educators in higher education with insights on how to impact teachers' actual practice by showing some episodes in which teachers transformed their inquiry experiences into instructional strategies that they wanted to use in their future practice.

Theoretical Framework

The goal for implementing the professional development program in the present research was to impact science teachers' attitudes towards inquiry in such a way that they want to increase the use of inquiry in their classrooms. It would be reasonable to expect that teachers will increase the use of inquiry in their classrooms when teachers themselves have positive learning experiences with inquiry. Therefore, a blend of constructivist (von Glasersfeld, 1995; Vygotsky, 1978) and constructionist (Papert, 1991) theoretical frameworks used in this study identified four elements that have to be included in the instructional program: (a) scientific inquiry activities associated with concrete materials, (b) participants' self-directedness, (c) instructors who support participants' knowledge construction as guides and co-constructors, and (d) discussions among peers. The primary focus of our program was the processes of scientific inquiry with the help of technology. However, the content of scientific inquiry was also well attended by instructors and participants in order to make the investigations meaningful, thereby the outcomes of the investigations were compatible with socially accepted scientific knowledge (Driver, Asoko, Leach, Mortimer, & Scott, 1994). This last point would make teachers feel more comfortable in bringing their inquiry experience in their classrooms, where teachers are normally concerned with teaching content described in the curriculum (Anderson, 2002).

The guided inquiry approach was used to develop activities in the program. The term *guided inquiry* refers to the practice in which teachers provide students with certain amount of help to develop inquiry investigations in the classroom (Martin-Hansen, 2002; NRC, 2000). Usually, teachers choose the question for investigation. The degree to which teachers structure what students do depends on the students' abilities and readiness to conduct inquiry investigations. The guided inquiry approach was most suited in the present program because it allowed participants to take self-directed steps within the scope of the given questions. The tasks that were associated with the questions must be suited for the use of data-loggers and available sensors. The tasks were also chosen in such a way that they would be scientifically challenging to the participants, yet easy enough for them to bring the experiments back in their classrooms.

The professional development program implemented in this research incorporated an explicit pedagogical component that transforms teachers' inquiry experiences into teaching practice. It has been pointed out that teachers' inquiry experience alone would not lead them to develop teaching strategies for inquiry-based lessons (Crawford, 1999). In the present professional development program, a significant amount of time was allocated for the development of effective lesson plans for teaching scientific concepts that teachers themselves learned through inquiry processes. Through explicit discussions about teaching strategies, it was expected that the participants would be able to develop more realistic views toward the actual practice of bringing the inquiry experiences into their classrooms.

METHOD

Research Methods

The primary research method was qualitative investigation. The ways how participants went through the processes of scientific inquiry were studied qualitatively. Qualitative data consisted of field notes, video recordings, participants' written notes, lesson plans, sensor data and interpretative graphs that the participants generated during the course of their inquiry activities. As a whole, qualitative data provided information in the context of the professional development program, including the mutual interactions among the content, the instructors, and the participants. Participants' attitudes toward the use of inquiry in science teaching were measured by a survey instrument. The pre- and post-program surveys included a question regarding the feasibility of the use of inquiry in classroom. The quantitative data was used to support the results found in the qualitative data.

Participants

The unit of the analysis was science or technology teachers who participated in one of three separate workshops offered in the US and Japan.

This study included 10 American teachers and 18 Japanese teachers. The first workshop (US1) was offered in an urban city in Massachusetts in June, 2007. Six science teachers from local middle-schools participated in the 3-day workshop as an opportunity to learn how to use data-loggers in scientific inquiry. The second workshop (JW) was held at a high school near Nagoya, Japan in December, 2007. A total of 18 teachers from elementary, middle, high schools, and colleges participated in the workshop. They were science or technology teachers at schools in various places in Japan. They attended the workshop as members of a teachers' organization whose aim is to promote the use of technology in education. The third workshop (US2) was held at a middle school in an urban city in Massachusetts. Four science teachers participated in the workshop as a part of their professional development activities in August, 2008. Both JW and US2 lasted two and a half hours.

Professional Development Program

A learning cycle format (Atkin & Karplus, 1962; Lawson, Abraham, & Renner, 1989) was embedded as the instructional framework of the professional development program. The format follows in three phases: exploration, concept introduction, and concept application. Figure 1 illustrates the logic model of the learning cycle format used in this study.

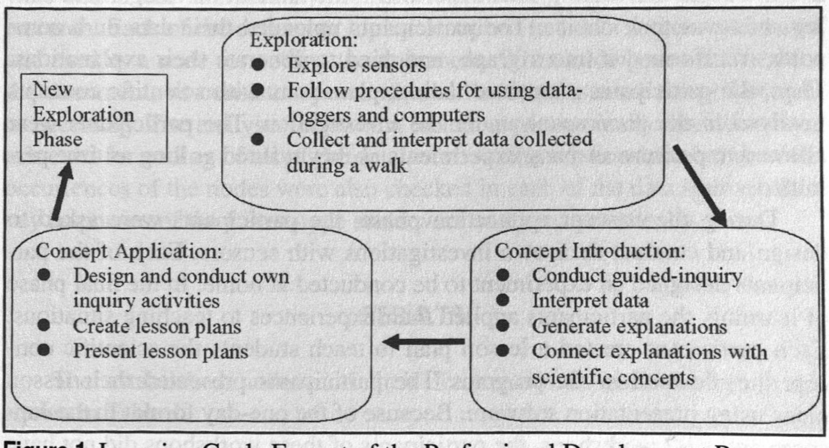

Figure 1. Learning Cycle Format of the Professional Development Program

During the exploration phase, the participants explored the data-loggers and probes, and discussed what physical quantities the probes were measuring. Using an LED numeric display that showed sensor values in real time, the participants learned how the data-logger measured the quantities of interest. Temperature, light, and infra-red sensors were provided for the participants to investigate. The participants also received instructions about how to use data-loggers with computers. They learned how to configure the apparatus for data collections with one or two sensors. During this phase, they performed a simple data-collecting activity with light and temperature sensors; the participants took a 10-minute walk inside and outside of the building with the data-loggers in their pockets and sensors connected to them. The course of the walk was selected by the researchers in such a way that the activity would yield data that would involve a contrast between bright and dark places as well as warm and cold places. Back in the classroom, the participants uploaded their data on computers and transformed the data into graphs. Each participant tried to explain the graph; they interpreted their graphs by making connections between their sensory experiences and the ups and downs of the graph lines.

During the concept introduction phase, the participants conducted guided-inquiry experiments such as mixing vinegar with baking soda in a cup. Each two participants formed a team and chose the activities they wanted to do. Even though the participants started with the given questions and materials, the details of the experimental design were up to them. For example, in the vinegar-and-baking soda experiment, the amount of vinegar and baking soda was their choice. The participants uploaded their data on a computer, transformed it into a graph, and tried to generate their explanations. Then, the participants connected their explanations with scientific concepts involved in the phenomena under the investigation. The participants were allowed to perform as many experiments as they wanted as long as time permitted.

During the concept application phase, the participants were asked to design and conduct their own investigations with sensors. Each of the participants designed an experiment to be conducted at home. In the final phase of learning, the participants applied their experiences to teaching situations. Each participant created a lesson plan to teach students the scientific concept they learned in the program. The participants presented their lesson plans using presentation software. Because of the one-day format in the Japanese and US2 workshops, the participants of these workshops did not have time to generate lesson plans. Instead, the instructors led their discussions after the guided inquiry activities in such a way that they could extend their thoughts to their inquiry-based teaching practice.

Data Collection and Analysis

Two researchers were involved in data collection. They were also instructors of the workshops. The US1 and US2 workshops had other instructors who were not a researcher. A video camera recorded the activities in US1 workshop. Video recording in JW and US2 workshops was taken by persons who were not involved in the research while the researchers were focusing on conducting workshops. The field notes were written after each of the workshop by one of the researchers through viewing the videotapes. Participants' conversations that were associated with inquiry activities were transcribed and included in the field notes. Participants' written notes and other data that were generated during the activities were collected by the researchers. Lesson plans, scientific inquiry logs, and reflections were collected in US1. Survey responses before and after the program were collected in US1 and JW. Survey was filled only after the program in US2 workshop. Printed copies of all graphs generated during the workshops were retrieved from an internet site in which all the numerical data for inquiry activities was created and stored. The internet site was specifically created by the researchers to serve for the purpose of the data collection activities with the data-loggers.

All these research data enabled the researchers to interrelate tasks, participants' actions, and instructors' actions during the course of activities. The field notes, participants' written notes, and open-responses in the survey were coded and analyzed by the researchers using software for qualitative research. Each of the actions or topics described in a data source was named and used as a node for coding the document. When coding was finished for the document, its consistency was checked and nodes were merged or split as necessary. The analysis followed a recursive pattern until consistency was achieved for coding of all of the data sources. The relationships between the occurrences of the nodes were also checked in each of the data sources. Survey responses of the Likert-type scale were analyzed statistically.

RESULTS

The established nodes and their frequencies in each workshop are shown in Table 1.

Table 1
Names of Nodes and the Numbers of Observed Instances in Each Workshop

Name of the node	The number of observed instances			
	Total of all 3 workshops	US1 (N=6)	JW (N=18)	US2 (N=4)
1. Teaching strategies	43	24	13	6
2. Participant's own ideas	42	37	1	4
3. Guiding inquiry	31	14	11	6
4. Graphs	29	17	5	7
5. Instructors' technology guidance	26	19	1	6
6. Experimental design	26	22	2	2
7. Explanations	23	14	7	2
8. Motivation	20	12	7	1
9. Discussions	19	11	3	5
10. Sensors	18	8	9	1
11. Comfort	17	14	0	3
12. Connections to sensory experiences	11	5	6	0
13. Hardware problems	8	5	3	0
14, Effectiveness of technology	8	2	5	1
15. Hesitation	7	3	0	4
16. Hypotheses/ Predictions	5	2	2	1
17. New insights	2	2	0	0

The pattern of the numbers of the instances varies according to each of the workshops, reflecting the differences in the workshop format, participants, and the content. The US1 workshop was a 3-day format. The participants in the workshop could spend more time for testing their own ideas to design their experiments and to formulate explanations of the phenomena than the participants in other workshops. In the Japanese workshop, the majority of the participants were technology teachers. They needed little guidance in technology. Since the main focus of the Japanese workshop turned out to be individually testing three kinds of sensors, the occurrence of the topic of "Sensors" shows the high value. In US2 workshop, on the other hand, the focus was on the table-top experimental activity of mixing vinegar and baking soda in a cup. All four participants in US2 workshop conducted the same experiment. Therefore, the participants in US2 workshop had more time discussing variables and results than Japanese teachers.

In spite of the variations, there were common features in the processes of learning inquiry in all three workshops. The findings from the analysis are presented as three assertions. The statement of each assertion is presented first. Then, the vignettes and excerpts from data sources follow to further illustrate the assertion.

Assertion 1. Participants' own exploration within the guided-inquiry activities, instructors' guidance, use of data-loggers, and discussions among participants contributed positively to their engagement in the investigations.

This assertion summarizes the elements that helped the participants engage in inquiry activities in the workshops. The elements were identified based on the results shown in Table 1. "Participants' own ideas" was ranked second and "instructors' guidance" was third and fifth of the most frequently referred topic. "Graphs" was ranked fourth and "discussions" was ranked ninth. While each of the elements played an important role by its own, the relationships among elements played a crucial role for bringing an inquiry atmosphere into the workshops. The explanations of each element and its connections to other elements are presented below.

The professional development program in this study did not provide participants with detailed instructions of the activities. The participants had to decide their own steps within the range of given tasks. Even with the first activity of checking sensors, the participants were asked to do something of their choice to see what physical quantity the sensors were measuring. The following episode shows how the activity made the Japanese teacher explore the infra-red sensor.

> One of the participants was trying to figure out the infra-red sensor. He held it facing downward and upward, and didn't see much of a change in the readings. Then he put the sensor under the table. The values went up and down. He couldn't see any pattern. Then another participant suggested that he should place the sensor in a tin can. They did. The display showed small values. (JW Field Notes)

As in the case of the above episode, when the participants were exploring something, discussions among peers naturally took place. Through discussions, the participants often generated new ideas to test their hypotheses. They could also identify the weakness of their experimental design. In the following description taken from the US2 field notes, each of the participants used different amount of baking soda and vinegar. They also poured vinegar in different ways in the cups of baking soda. When they saw four line graphs on the same screen, they discussed how the amount of vinegar and baking soda affected their graphs.

Participant B: "More baking soda or more vinegar, which works better?"

Instructor 1: "Do you think you can decide that from this set of data?"

Participant B: "I don't know because there are so many measurements."

Instructor 1: "Would there be more factors you have to think about?"

Participant B: "Yes, yes."

Participant A: "I think we all have the same amount of baking soda and vary the amount of vinegar."

Participant C: "That's right."

Participant A: "Or use the same amount of vinegar and different amount of baking soda. Since we were all separate in the amount of baking soda AND vinegar, I think it was hard to compare each of our data on there."

Participant B: "And adding more vinegar, sort of tortured the graphs."

Instructor 1: "The first experiment is a kind of trial run. You find out what kind of factors you need to look for and mind for."

Instructor 2: "Definitely. Constructing an experiment is a hard problem." (US2 Field Notes)

After this conversation, the participants of US2 workshop decided to redo the experiment by fixing the amount of baking soda and varying only the amount of vinegar. This episode shows an example of social construction of knowledge; the participants as a group generated a meaningful explanation with the help of instructors. One of the participants of US1 workshop summarized the role of discussion as "Discussion is important to formulate ideas, to interpret results, and to use the data-logger as a tool" (US1 Survey Open-Responses).

It should be noted that the instructors' role in the program was dual; they provided guidance in the inquiry activities as well as in the use of technology. When instructors provided guidance in a timely manner, participants could do their computer tasks without difficulty. Their anxiety was often converted into comfort in our workshops.

The level of comfort in the pace of conducting inquiry activities also varied according to the participants. For example, when the US1 workshop started, a participant expressed her uncomfortable feeling with the pace of the workshop. However, as the workshop progressed, the guided-inquiry aspect of the workshop helped her build more positive feelings. At the end of the day, she wrote "Enjoyed testing out ready-made experiment. Why: still guided activity as I was not sure of how all aspects of the program worked" (US1 Reflections on Day 1).

Instructors' role for guiding participants' inquiry activities was not limited to providing activities. When the discussion went to a dead-end, the instructors prompted the participants through questioning and helped them find a different direction that would bring them more scientifically meaningful explanations. The instructors were sometimes co-constructors of knowledge; the participants and instructors generated explanations together. The instructors also often helped participants design experiments. When participants design an experiment for the inquiry activity, they often have difficulty because they would not yet know the scientific concepts that are involved in the experiment. Instructors' guidance and discussions were an essential component in designing experiments in authentic inquiry activities.

The effectiveness of the use of data-loggers stayed as a backbone of the program. The use of data-loggers enabled the participants to collect data that would not be available with conventional instruments. The following conversation in US2 illustrates how the participants became more aware of the effectiveness of the use of the data-loggers through a discussion.

> Participant B: "Can we do the same thing with regular thermometers and stopwatches?"
> Participant C: "Then, students have to make their own graphs."
> Instructor 2: "Capturing every second would be a bit faster than they could do manually."
> Participant A: "How about in every 5 seconds?
> Participant C: "But chemical reaction goes so instantaneously." (Everyone nodded.)
> Instructor 2: "Kids love to see the graphs anyway."
> Participant B: "That's for sure." (US2 Field Notes)

Besides the measurement capability, computer's capability of quickly converting data into graphical forms enabled the participants to visualize data immediately after the experiment. This capability generates participants' motivation in inquiry activities. Furthermore, the graphs helped participants understand the meaning of the phenomena. This leads into the second assertion.

Assertion 2. Participants' sensory experiences and their connections to graphical representation of data led them to having new understanding of the phenomena.

The following episode shows an excitement of a Japanese teacher when he saw that his data was quickly converted into a graph.

Participant: "This is great! This is interesting! Wow!"
Instructor 1: "Can you tell the meaning when you look at it?
Participant: "Like it was inside here, and I went outside here?"
Instructor 1: "Yes, what does the graph mean? Can you explain it?"
Participant: "Yes, explanation. I can explain it."
Instructor 1: "Yes, here the temperature stayed the same, but the light changed. Something different must have happened."
Participant: "It must be in the shade." (JW Field Notes)

In this episode, the graphical representation (Figure 2) easily led the participant to generating an explanation of data. When he figured out that he must have been in the shade, he made a connection between his experience and the graph. More incidences of making connections between participants' sensory experience and the graph for understanding the meaning of phenomena were observed during the workshops (See Table 1). The importance of making connections between sensory experiences and graphs in the process of inquiry was not recognized previously in literature.

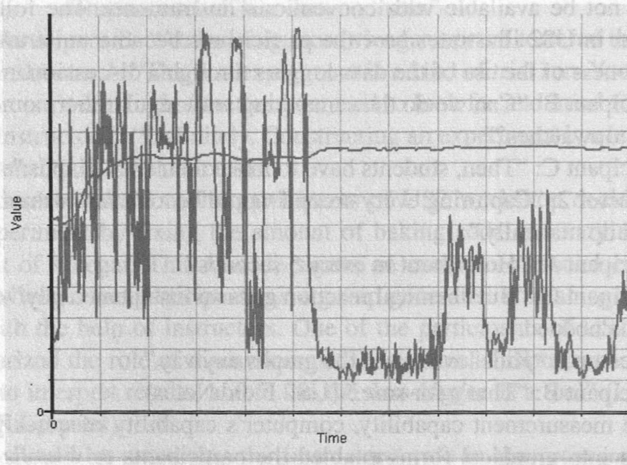

Figure 2. Graphical representation of temperature and light data produced by a participant in JW

For the Japanese participants, who were mostly technology teachers, the use of electronic sensors in revealing the properties of their surroundings was new. One of the participants mentioned in the survey response that "It was interesting that we could become aware of things in our surroundings by transforming their properties into graphs and numbers" (Survey results). Two more participants submitted similar responses. A Japanese participant further noticed that "the data-logger can present data that we cannot recognize through our senses and cognition. I noticed the difference between the measurement and human sensory input. I also learned that data in real-world is continuous and analog" (Survey results). For these participants, the transformation of their sensory experiences into abstract data and the comparison between the two gave them new insights into the nature of scientific measurement.

Furthermore, during the US1 workshop, episodes were observed when the connections between participants' sensory experiences and the graphical representation played a crucial role for providing the participants new understanding of the phenomena under the investigation. One of the incidences occurred during an experiment in which the participants decided to detect a light emission using the data-logger from mint-flavored candy when it was crushed in darkness. Participants 1 and 2 could not detect light using the data-logger. They ran the experiment three times with different settings, but the graphs did not show any signal detected by the sensor. The following excerpt shows what they did in the situation.

> Then, they decided to see light by themselves by going into a dark closet and breaking a candy. They found glow-in-the-dark type light from the candy, but the data-logger didn't detect the light they saw. Participant 2 started to look for information about light from the candy on the Internet. (US1 Field Notes on Day 2)

This vignette shows how their actual sensory experience made the participants realize where the problem was. Before the experiment in the closet, they were thinking that they could not detect the light because of their experimental design. Through the sensory confirmation, they discovered that it was the capability of the sensor itself that was causing the problem. Participant 2's excitement of the discovery was reflected in her action of rushing to the computer to look for information about the light emission on the Internet. She also noted her discovery in her reflection as "Life-Saver gave me an opportunity to test the data-logger and compare data to my observed data" (US1 Reflections on Day 2). Participant 1 also wrote in her reflection as follows.

> Life-Saver investigation was really interesting. I liked thinking thoroughly how to set up the experiment, making the design so that the photo cell would work in darkness. Even though it was unsuccessful in finding the spark, it was educational to work through. (US1 Reflections on Day 2)

It can be inferred that the activity gave them not only new understanding of the phenomena but also new insights into the nature of scientific inquiry.

Another incidence in which a connection between sensory experiences and graphical forms played an important role happened in US1 workshop. Participant 3 and 4 were measuring a temperature change in an experiment of producing fog in a plastic bottle. They were instructed to pour a small amount of rubbing alcohol in the bottle, place a rubber stopper at the bottle neck, and pump air through the hole in the stopper using an air pump. When they unplugged the stopper suddenly, they saw fog in the bottle. The following excerpt from the field notes illustrates how the participants went through the investigation.

> The graph showed that the temperature increased while they pumped, and decreased when they took the plug. Instructor 1 asked them what the explanation of the fog was. They understood the temperature change associated with the pressure change, but they were unable to make a connection between the fog formation in the bottle and the decrease of the temperature. Instructor 1 asked them a series of questions to guide them. Participant 3 realized that fog was made of liquid droplets. From there, they built their understanding of how fog was produced in the bottle when the pressure suddenly changed. The question of why they used alcohol instead of water came into the discussion. They did an experiment with water. Fog didn't appear, but the graph showed the same pattern of temperature change. They started looking for information on the Web. Participant 4 found that the boiling point of isopropyl alcohol was lower than that of water. (US1 Field Notes on Day 2)

In this episode, before the experiment with water, the participants did not understand fully why fog was produced with a decrease in temperature. Perhaps they have had associated fog production with higher temperature in the bathroom, for example, and the fog formation with a temperature decrease might not have made sense to them. When they saw no fog but still the same temperature pattern in the experiment with water, they could separate temperature change from the fog formation. They could attribute fog formation to the properties of alcohol. It was interesting to note that in this episode also the participants wanted to look for scientific information to support their reasoning. It seemed that they naturally wanted to construct knowledge as the ultimate goal of their investigations. As soon as they came to know what knowledge they desired, they rushed to get it from a reliable information source.

Assertion 3. There were strong connections between participants' positive experiences about inquiry and the teaching strategies that they wanted to incorporate in their science classes.

Table 1 showed that teaching strategies were frequently mentioned in all three workshops. From the start of the workshops, the teacher-participants were concerned with how they could use their learning experiences into practice. The following description illustrates how the participant was looking at the processes of inquiry as a teacher who teaches students:

> I liked how the activities progressed from first investigating what the data-logger does, to using it to collect raw data, and then finally using it doing a more structured lab activity. It helped me understand how I could help my students understand how to use them. The developmental approach helped build understanding. (US1 Reflections on Day 1)

Many of the Japanese teachers also mentioned about student learning in their survey responses; four teachers wrote that the use of data-loggers could motivate students in learning science (Survey Results). These examples show that the workshop participants generally had students in their mind while they were going through their own inquiry experiences.

When participants in US1 workshop were asked to prepare a final presentation based on their inquiry experiences during the workshop, each participant created a presentation with an emphasis on different points. Participant 2 used her experience with the mint-flavored candies to write a lesson plan for teaching the experiment. The teacher elaborated the experiment by placing it in a context; she named the project as "Myth Buster" in which students would verify the correctness of scientific ideas that were told to be true. Participant 5 and 6 also wanted to transform the inquiry experience that they had during the workshop into a lesson plan. They wanted students to test how weight and length of pendulum would affect its period in a similar way as they did in the workshop. Furthermore, they wanted to place the activity in a context of movie characters by naming it as "Get Tarzan and Jane home quickly". In fact, Participant 5's reflection indicated a connection between her positive experience and the context; "I did the pendulum activity. It was fun experimenting with the variables and the design to minimize interference. I liked applying this to a real world situation" (US1 Reflections on Day 2).

On the other hand, the fog experiment did not motivate Participants 3 and 4 to write a lesson plan on the topic. They chose other experiments that they did at home as topics for lesson plans. Perhaps the variables involved in the fog experiment were too complicated for them to feel comfortable in implementing the activity in their classes.

Table 2 shows the results obtained from the survey. The participants indicated their feelings toward the feasibility of inquiry-based lessons in their classrooms in five options: strongly agree = 5, agree = 4, neither agree nor disagree = 3, disagree = 2, and strongly disagree = 1. The average scores and the standard deviations are shown in the table. The number of sample (N=17) indicates the number of participants who responded both pre-program and post-program surveys.

Table 2

Participants' Feelings Toward Feasibility of Inquiry-Based Teaching Before and After the Program

	Pre-program survey (N=17)	Post-program survey (N=17)	Significance of difference
Average score	4.29	4.76	0.266
Standard Deviation	0.59	0.44	

Table 2 shows that after the program, the workshop participants agreed more strongly with feasibility of inquiry-based teaching in their classrooms than they did before the program. This result was consistent with the findings in qualitative data in which only positive feelings toward the use of inquiry was observed during the course of the workshops. However, the difference between the pre- and post-program survey results was not statistically significant ($p>.05$). In addition, the small sample size puts a limitation on the use of statistics in this study. The positive effect of the program remained to be inconclusive in the statistical analysis.

DISCUSSION

This study showed how a professional development program impacted participants' attitudes toward inquiry-based teaching through the use of data-loggers. The program included guided-inquiry activities, learner's self-directedness, instructors' guidance, and explicit discussions about teaching strategies as the elements for aiming to promote participants' autonomous learning in scientific inquiry as well as the development of strategies for inquiry-based teaching. The results indicated that each of the elements provided by the program contributed positively to building up participants' inquiry experiences. The inquiry experiences further led the participants to generate new insights and understanding of the nature of scientific inquiry. These new insights and understanding were then transformed into inquiry-based teaching strategies that they wanted to use in their classrooms. Figure

3 summarizes the overall logic model of the program and what participants generated in the program.

Although the full range of data-collection took place only in one workshop, this study identified trend that was common in all three workshops regardless of the cultural settings in which the workshops were held. It was interesting to note how the elements offered by the program were tied together; the elements affected participants' inquiry activities not as a single incidence but as a sequence. For example, in the baking soda and vinegar experiment, the participants in US2 workshop had to discuss the amount of materials they would use for their experiment. The choices that were given to the participants generated discussions. The different amount of materials produced differences in the results which were visible with the help of graphs that the computer generated immediately. Lively discussions started and an atmosphere that promoted inquiry was created. With instructors' prompts, they could even found the importance of controlling variables in inquiry activities through the discussion. This study found that guided-inquiry activities, learner's self-directedness, instructors' guidance, and the use of technology were all linked together in creating rich inquiry experiences for the participants.

It was also interesting to find that participants were more likely to be convinced when their sensory experience confirmed the results that they obtained through data-loggers. The numbers and graphs that the data-logger produced were abstract in nature. This study witnessed a number of incidences in which data-logger users had a better understanding of the meaning of the abstract data when they could relate it with their own sensory information. Perhaps the use of electronic sensors enabled the researchers to observe this effect more easily. However, this finding may not be limited to the cases in which electronic sensors and data-loggers are used. The use of numbers and graphs is the same in the case of using traditional instruments. Thus, the finding suggests that even using traditional measuring instruments like regular thermometers, learners would be able to have a better understanding of the meaning of data when they relate the data with their sensory experiences. This finding further suggests that science teachers may be able to help students' understanding of the meaning of the phenomena more effectively by consciously making efforts to connect data with students' sensory experiences.

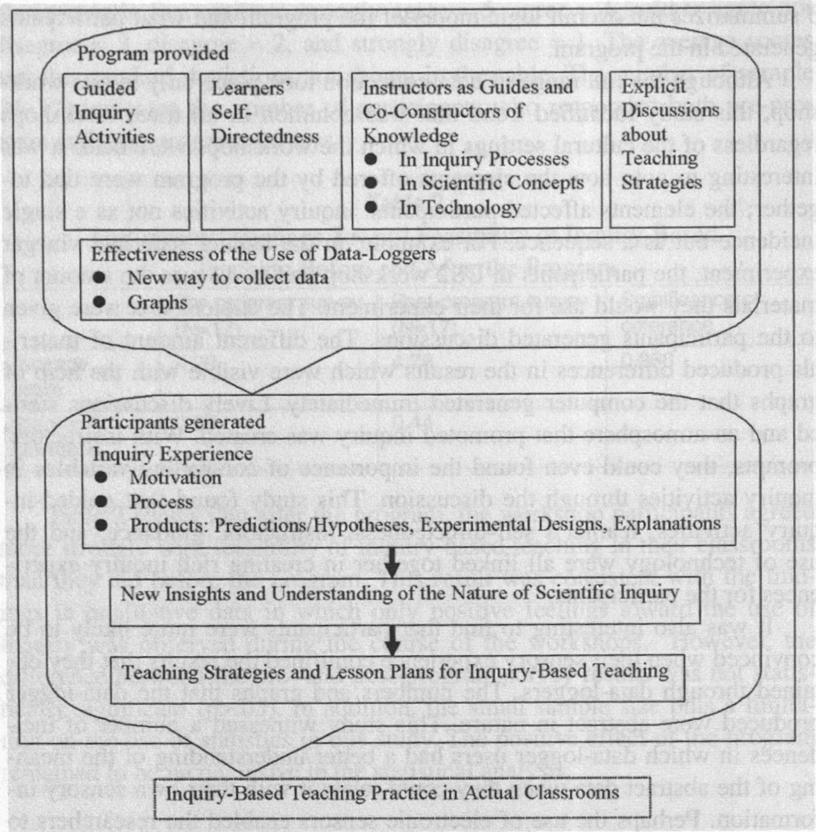

Figure 3. Logic model of the professional development program used in the study.

The ultimate goal of the professional development program was to have teachers use inquiry-based teaching in their classrooms. The explicit discussions about teaching strategies were well-received by the participants. From the start of the workshops, they were interested in how their inquiry experience could be used in their classrooms. The explicit discussion about teaching helped them externalize their thought about transforming the inquiry experience into teachable forms. This study showed that when teachers' inquiry experience brought new insights and understanding of the nature of scientific inquiry through an investigation of a phenomenon, they were more likely to generate lesson plans and teaching strategies about the activities they liked. However, the strength of the impact on their willingness of the use of inquiry in teaching seemed to depend on the depth of their inquiry experiences in three aspects: motivation, processes, and scientific concepts. The teachers expressed willingness of the use of the activities in classroom when they themselves felt comfortable and interesting with the activities (motivation). Moreover, the teachers wanted to implement the activities in their classroom just as the ways they experienced the processes in the workshop (processes). Furthermore, they were more likely to express their willingness of the use of the activities when they thoroughly understand the scientific concepts that were involved in the activities (scientific concepts). In order to increase the possibility of having the teachers implement more inquiry-based teaching, instructors in professional development programs should make every effort to raise the participants' level of comfort in all three aspects. With this finding identified, the professional development program in the present research should also be revised for improvement.

As an extension of the research, classroom observations of the participants have been planned and conducted. It would be interesting to see how the workshop participants actually implement inquiry-based lessons using data-loggers in their own classrooms. The research is underway and the results will be published in future. The results will further inform the researchers how to improve the professional development program, and support teachers in modifying their teaching practices.

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