Pre-service training program to enhance chemistry teachers' teaching abilities and skills: Development of a Q&A leaflet and pH experiment kit

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Abstract

Lesson study has been actively carried out in many Japanese schools, and teachers have been important in terms of answering students' questions in class. Studying and implementing programs based on the themes of high school students' and science teachers' questions may enhance pre-service chemistry teachers' abilities and skills. This study aimed to better understand usage of Information and Communication Technologies tools for teaching during a pre-service training program. First, we selected a theme related to the pH of a weak acid, about which many Japanese high school students have queries. Second, we created a chemistry Q&A leaflet and developed a pH experiment kit related to this theme. Finally, a video explaining pH using the experiment kit, and a video calculating the pH level in an easy-to-understand way, were also developed and posted on YouTube. The results of this study provide pedagogical implications for the training of science teachers.

Keywords: pre-service training; chemistry teaching materials; Q&A; pH

Introduction

There is much value in addressing the questions that students raise in junior high and high school science classes, as well as the queries of teachers in relation to the progression of their classes. Examination of these themes is useful in enhancing the teaching abilities of students aspiring to be junior high and high school science teachers. Lesson study has been actively carried out in many schools in Japan, and Japanese teachers are important in terms of answering students' questions in class. Japanese teachers learn the techniques of lesson study from each other, and this style of learning has been so successful that is has spread internationally.

However, the main feature of Japan's science education is its focus on observation and experiments. At all school levels, it is understood that students will complete observations and experiments, and textbooks and courses of study often encourage these teaching methods. Although a variety of teaching materials for observations and experiments can be obtained through the Internet and used during preparation for science classes (such as through the Science Network or the Science Channel), the type of materials used differs among junior high and high school science teachers. Whether or not

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these materials are effectively used in schools depends on the teachers' skills.

Using Information and Communication Technologies (ICT) tools in the classroom contributes to the creation of a powerful learning environment in which teachers are more likely to implement constructivist teaching approaches (Judson 2006; Shieh, Chang, and Tang 2010). Teaching programs must recognize the importance of questions and queries for students who aspire to be science teachers. They should also be of the inquiry type, in which problems are addressed using trial and error (see Stage 3 and Stage 4 of the method section). There is much value in a program to train junior high and high school science teachers to enhance their teaching abilities, by developing answers and experiments to satisfy students' frequently asked questions and queries that teachers have regarding the progression of their lessons.

There were multiple goals of the current teacher program being developed. Themes were determined based on queries that aspiring science teachers had when they were at high school, and that they also thought were important from the point of view of science teachers. Aspiring science teachers created a 'chemistry Q&A leaflet' and 'pH experiment kit', and recognized the need to be aware of junior high and high school students' queries, and the importance of continually enhancing their own teaching abilities so as to be able to answer those queries. The results are used to suggest guidelines for developing teaching programs for pre-service and beginning teachers.

Method

Stage 1: Selection of questions and queries

We selected 80 questions relevant to the content of the current high school science textbook 'Basic Chemistry' from among 382 chemistry-related questions and queries frequently raised by high school students and teachers in Japan. The Chemical Society of Japan collected many chemistry-related questions and queries from junior high and high school science teachers in the 1990's, and published these in the monthly 'Chemistry and Education' book. Of the 382 questions and queries, 143 were collected from the book 'Chemistry Questions & Answers from the Classroom' edited by The Chemical Society of Japan (2002). The remaining 239 questions were chosen from now out-of-print books created by the private study group of Fukuoka and Kumamoto Prefecture (Nakamura et al. 1987; Matsubara, Uryu, and Otsuka 1990).

Three of the above books were not utilized in the teacher training program, but rather for understanding the needs of aspiring science teachers for ICT applications. By leveraging the results of educational research in Japan, the program is designed to improve course instruction among aspiring teachers.

Stage 2: Consideration of questions and queries

Participants at the second stage of the program were 62 third-year students in the faculty of science at Toho University, from the departments of physics, chemistry, biology, biomolecular science, and environmental science. During June 2013, we asked these students to spend 15 minutes selecting queries they had as high school students or issues that they judged to be important from the point of view of a science teacher, from the 80 questions and queries selected at the first stage. If there was a question or query other than those selected at the first stage that students wished to include, they were asked to write it down.

Stage 3: Composing answers and planning an experiment kit

In relation to the theme determined at the second stage, aspiring science teachers (23 third-year students in the faculty of science at Toho University, including 16 chemistry students) were asked to compose answers to the queries that would satisfy high school students. This process was conducted during July 2013. They were also encouraged to consider an 'experiment kit' that would support, through experiments, the process of high school students resolving the queries.

Stage 4: Completion of the 'chemistry Q&A leaflet' and 'experiment kit'.

At the fourth stage, three second-year students in the chemistry master's program at the graduate school of science at Toho University, scheduled to be employed as teachers in state junior high and high schools in April 2014, were asked to complete the 'chemistry Q&A leaflet' and the 'experiment kit'. In addition, they were asked to design, conduct, and record a tutorial and upload the video of the tutorial on YouTube. This process was conducted in October 2013 and took 30 hours.

Additionally, a column on 'neutrality' was written by a professor from the department of chemistry's 'Laboratory of Analytical Chemistry'. The contents were such that a high school student would understand that although normally a state of pH = 7.0 would be neutral, if the solvent is anything other than water this may change. For example, in ethanol, neutral is pH = 9.4, and in glacial acetic acid, neutral is pH=7.2. The goal of this column was to show aspiring science teachers that there are alternative methods of transmitting knowledge, beyond in-classroom instruction.

Results and Discussion

Stage 1: Selection of questions and queries

The content of the 80 questions selected included acids, bases and electrochemistry; liquids, solids, and phase change; covalent bonds; ion bonds; periodicity; the electronic structure of atoms; and the structure and stability of atoms.

Stage 2: Consideration of questions and queries

The results of the survey conducted with aspiring science teachers in relation to the 80 questions and queries related to the content of 'Basic Chemistry' are shown in Tables 1–3. Tables 2–4 show that the query 'However much an acid is weakened, its pH does not increase above 7. Similarly, however much an alkali is weakened, its pH does not drop below

Table 1. Queries as a high school student (62 students from all departments)

	Question	Percentage
1	Why do electrons orbit the nucleus?	41.90%
2	Why can copper be Cu^{2+} or Cu^{+}?	38.70%
3	How was the atom discovered?	37.10%
4	How does a flame test occur?	37.10%
5	Why can a solid change directly to a gas? (sublimation)	37.10%

Table 2. Queries regarded as important from science teachers' point of view (62 students from all departments)

	Question	Percentage
1	Is the volume of 1 mol of gas at 0°C always 22.4L at 1.013×10^5 Pa?	35.50%
2	How do you distinguish ionic bonding from covalent bonding? How do you distinguish via the chemical formula and from looking at the material itself?	33.90%
3	Is an ionization tendency the same as the ionization of energy?	30.60%
4	Why can copper be Cu^{2+} or Cu^{+}?	29.00%
5	However much an acid is weakened, its pH does not increase above 7. Similarly, however much an alkali is weakened, its pH does not drop below 7. Why?	29.00%

Table 3. Queries as a high school student (16 students from the department of chemistry)

	Question	Percentage
1	How does a flame test occur?	50.00%
2	Regarding the phenomenon known as sublimation, why is a direct change of state from a solid to a gas possible, and conversely from a gas to a solid?	37.50%
3	However much an acid is weakened, its pH does not increase above pH 7. Similarly, however much an alkali is weakened, its pH does not drop below 7. Why?	37.50%
4	How can we tell that matter is made of atoms and molecules?	31.30%
5	What are the names of the electron shells, such as the K-shell, L-shell, and M-shell, derived from?	31.30%
6	Why can copper be Cu^{2+} or Cu^{+}?	31.30%
7	Can diamonds be artificially synthesized?	31.30%
8	While water molecules must create molecular motion, why does this not produce waves?	31.30%
9	How do we know that $[H^{+}]\,[OH^{-}] = 10^{-14}(mol/L)^2$?	31.30%

Table 4. Queries regarded as important from science teachers' point of view (16 students from the department of chemistry)

	Question	Percentage
1	Around the neutralization point, why does the pH suddenly change?	37.50%
2	Is the volume of 1 mol of gas at 0°C always 22.4L at 1.013 x 10^5 Pa?	31.30%
3	However much an acid is weakened, its pH does not increase above pH7. Similarly, however much an alkali is weakened, its pH does not drop below 7. Why?	31.30%
4	Does the neutralization point have to be neutral?	31.30%
5	Is an ionization tendency the same as the ionization of energy?	31.30%

7. Why?' was fourth in terms of the queries that the students viewed as important from a science teachers' point of view in all departments, and second within the department of chemistry. It was also second (37.5%) among the queries that chemistry students had when they were in high school. The criteria to choose this theme were twofold. First, reagents and laboratory equipment could be easily prepared for this experiment. Second, the process of doing this experiment would be a valuable experience.

Stage 3: Investigating answers and planning an experiment kit

We decided to create answers and an experiment kit to help high school students understand the change in pH of a weak acid-base solution. Twenty-three third-year science students composed an answer comprehensible to high school first- and second-year students so that they would be able to resolve the query, 'However much an acid is weakened, its pH does not increase above 7. Similarly, however much an alkali is weakened, its pH does not drop below 7. Why?' The majority (55%) of answers were, 'Only a very small part of water (H_2O) is divided equally into H^+ and OH^- ions; therefore, however much it is weakened, the number of H^+ and OH^- ions added is equal, and since the difference between the number of H^+ and OH^- remains the same, however much an acid is weakened, its pH does not increase above pH7'. Among the answers, 16% included examples of everyday substances such as paint (pigment), thus it was evident that students recognized the importance of trying to make a connection with everyday life while using content studied at junior high school to help high school students understand. Their answers were suitable for third-year junior high school to first- and second-year high school students in Japan. In addition, 28% of answers included a calculation of a pH of 6.98 based on the fact that the ion product ($Kw = [H^+] [OH^-]$) in the water within a solution is maintained at a constant level, or from the chemical equilibrium of the electrolyte solution. Such content is only comprehensible to students who have studied the equilibrium of electrolyte solutions in the more advanced textbook, ‘Chemistry’. This is not a comprehensible answer for many first- or second-year high school students. In upper secondary school, pure sciences such as physics, chemistry, biology, and geosciences are divided into two levels, such as basic chemistry and chemistry. Students take the basic course first, and basic courses are composed of more elementary contents. Therefore, answers must be comprehensible to students at all levels.

Next, students were asked to think about an ‘experiment kit’. Most students (95%) suggested using a method of weakening a weak acid solution sequentially by factors of 10, 100, and 1,000 and observing the pH change of each solution. Among the suggested methods, using a pH meter was most common (50%), followed by using an indicator (28%), and using both a pH meter and an indicator (17%) (see Figure 1). The suggestions to use an indicator or both a pH meter and an indicator took into account the current lack of pH meters in science classes in Japan’s junior high and high schools. Approximately 40% of Japan’s junior high schools have no pH meter, and another approximately 40% use it only for demonstrations. Although we would like to see experiments conducted in chemistry lessons at regular high school classes using a simple pH meter readily available to all groups, there is a substantial gap in terms of availability at schools.

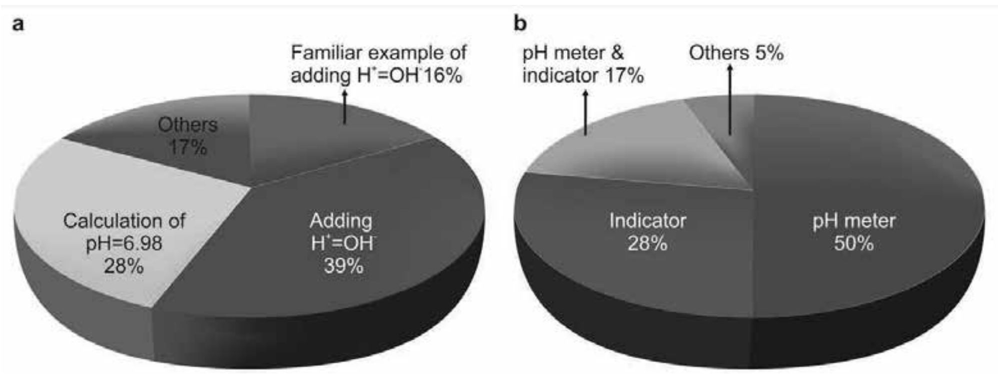

Figure 1. Proportions of responses regarding pH measurement method.

Most students suggested using hydrochloric acid or sodium hydroxide as an acid-base in the experiment kit. Others suggested acetic acid, citric acid, or sodium hydrogen carbonate. In terms of an indicator, suggestions included BTB solution, pH test paper, litmus paper, phenolphthalein solution, or liquid extracted from red cabbage. In this respect, it was once again evident that students recognized the need to make connections with everyday life while using the content studied at junior high school in helping high school students to understand.

Comments from aspiring science teachers indicated that they approached the development tasks by trial and error. The students’ responses are as below:

- ‘There are limitations as to what can be included in the experiment kit, so it was difficult to think of things that high school students would find interesting and that would also deepen their understanding’.

- 'It was very difficult to explain things that I had thought were obvious, as I was thinking up an accompanying empirical experiment'.
- 'I struggled as I thought that it was no easy task to get high school students to understand complex calculations. However, I think they will understand by conducting experiments, so it was good to think up an experiment kit'.

Stage 4: Completion of the 'chemistry Q&A leaflet' and the 'pH experiment kit'.

Graduate students gave the 'chemistry Q&A leaflet' the title 'Using the Power of Chemistry. Vol. 1'. They expressed their hope that, using the leaflet and experiment kit they created, high school students would find clues to resolving their queries and that high school students would in some way 'use the power of chemistry'(Course of Teacher Education 2013).

The leaflet had two types of answers. First, students created an answer using a model of the ion that would be comprehensible to junior high school students who had studied the junior high school chemistry unit 'Acids, alkalis, and ions'. Second, they created an answer for high school students who had studied the high school chemistry unit 'The balance of electrolyte solutions'. Third-year junior high school students in Japan study acid and alkali using hydrogen ion and hydroxide. Therefore, an answer directed at high school students who had studied the unit 'The balance of electrolyte solutions' would be too difficult for those just beginning high school chemistry (first and second-year high school students). In order to support high school students in the process of resolving their queries, video tutorials of the answers were posted on YouTube ('The basics of pH' and 'Weakening an acid will not make it alkaline. Why?'), and these videos could be viewed by scanning the leaflet's QR codes.

The pH kit (140mm × 75mm × 95mm) contained plastic receptacles (20mL × 2), small measuring bottles (10mL × 6), syringes (1.0mL × 2), a dropper (2mL × 1), bromthymol blue (BTB) solution (1mL), and purified water (100mL). The kit made it possible to easily experiment with changing the colour of an ascorbic acid solution (pH = 5) and a sodium hydrogen carbonate solution (pH = 9), diluted by factors of 10, 100, and 1,000, using a BTB solution (see Figure 2).

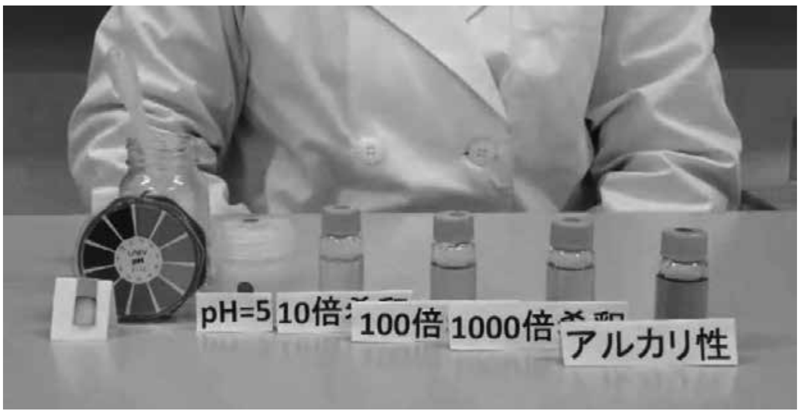

Figure 2. Experimental kit for diluting ascorbic acid and hydrogen carbonate (pH = 5; diluted by factors of 10, 100, 1,000; alkaline) .

The first characteristic of the kit was that increasing the pH from 1 to 2, 1 to 3, and 1 to 4 decreased the concentration of the solutions by 1/10, 1/100, and 1/1,000. Therefore, junior high and high school students were able to easily test the quantitative relationship between pH level and concentration of a solution at home. Currently, the percentage of academic staff in Japan 'asking students to conduct observations or experiments at least once a week' is 60% to 90% in elementary schools and 60% at junior high school, but by contrast, is low (approximately 10% or less) at high school, where observations or experiments by students themselves generally occur once a month or less (Japan Science and Technology Agency 2010). Hence, being able to easily conduct quantitative high school chemistry experiments at home is of major significance.

The second characteristic of the kit is that by using everyday substances such as ascorbic acid (vitamin C) and sodium hydrogen carbonate solution (baking soda), high school students can gain an understanding by linking experiments to everyday life. It is also a repeatable experiment because the substances are safe and easily available to high school students.

The third characteristic of the kit is that, as with the answers on the leaflet, the tutorial videos for using the experiment kit were posted on YouTube. These can also be viewed by scanning the QR codes, and the experiments can be carried out while watching the videos. The experiments were recorded in entirety and the videos were unedited, so the procedures of the experiment could be re-enacted as required. Hence, if following the videos exactly, even junior high school students would be able to carry out the experiments.

Because the three students worked together to address the task, each of their individual ideas were important, and it was effective to examine a student's proposal from the other two students' point of view. In addition, in relation to designing, implementing, and recording the tutorials, three types of tutorial videos were composed with content understandable to high school students. In particular, videos of 'The basics of pH' and the 'experiment kit' were sufficiently understandable even to junior high school third-year students who had studied acids and alkalis using hydrogen ions or hydroxide ions. This task seems to have provided a very useful opportunity for students to think deeply about what kind of lesson to design, and implement concerning themes raised in chemistry textbooks as 'references' in order to facilitate high school students' understanding. In addition, the students also reflected that they learned a great deal through the process of improving the quality of classes by mutually evaluating one another's proposals to resolve the task in the group, and incorporating guidance and advice from faculty members in science education on the teacher training course. We also heard some students' planning how to incorporate these methods upon becoming science teachers, such as, 'I felt that it was very useful to have the queries I had as a high school student explained in videos like these, and at some point I want to try planning these kinds of approaches myself'. Students who had created the 'chemistry Q&A leaflet' and 'experiment kit' indicated that it is important to become aware of junior high and high school students' queries and to enhance teaching skills to answer those queries.

The basic purpose of ICT education in junior high and high school is to make use of ICT to 'achieve the targets of each subject'. The use of ICT, which is positioned as a new method to provide 'attractive and easy-to-understand classes', is expected to improve academic ability and aid in the instruction of students according to their academic levels. In order to provide an excellent pre-service training program to enhance chemistry teachers, it is essential to improve teachers' ICT instructional ability. Based on the above-mentioned points, the use of an ICT program in conjunction with 'Lesson Study' instruction is an effective teaching method in Japan.

Conclusion

Within this pre-service teaching program, students aspiring to be science teachers approached development tasks by trial and error. The Japanese textbooks 'Basic Chemistry' and 'Chemistry' are concise and provide a good summary for high school students who are acquainted with chemistry. However, high school students who have just begun learning chemistry have many queries about content that they cannot understand. By conducting this teaching program, we were able to enhance the teaching skills of aspiring science teachers as well as acquaint them with the current situation and problem areas within chemistry education provided at junior high and high school. In the future, with the aim of providing 'teacher training of science teachers able to deliver high-quality teaching', we will continue this teaching program (in chemistry) for students aspiring to be science teachers, demonstrate the efficacy of this teaching program, and also conduct teaching programs within the disciplines of physics and biology.

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