pH Changes of River Water in STEAM: Practices of High School Chemistry and Science Club

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Abstract

The objective of this study is to share information about the practices of high school science club activities and chemistry classes. The author announced that the water pH of rivers in Japan sometimes indicated alkaline at the 9th NICE Conference in 2023. Why is the river water alkaline? Twenty years ago, his science club students and he started to investigate the water quality of rivers near their school. In STEAM education at his high school, he treats his teaching material "pH changes of the river water" as follows: Science includes chemistry, biology, geology, scientific method and simulation, etc., Technology and Engineering includes the way to use pH meters, the calibration of them, and wastewater treatment etc., Art includes environmental issues and its regulation, etc., and Mathematics includes calculations of exponents and logarithms, and so on. When he taught about the pH of chemistry using these materials above, the students were surprised at the alkaline river water with the experiment of the water quality test, and amazed at the pH change mechanism by photosynthesis.

Keywords: pH changes of river water, alkaline, STEAM education, teaching material, high school chemistry, science club

Introduction

STS education in the 1990s

STS education is an education that relates to Science, Technology and Society shown in Fig. 1. Many stakeholders, including scientists, exist in every domain of STS. Science, Technology and Society interact with one another. So, they are not value free.

In the author's educational experience, the environmental education was popular in Japanese high school in the 1990s. Shiokawa et al. and the author developed STS teaching materials about Minamata Disease [1] - [4], which included a training series of decision making and role plays.

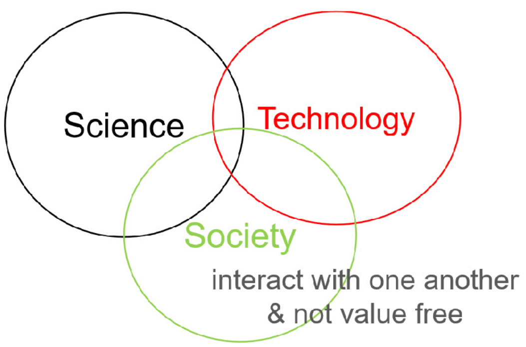

Fig. 1. STS education in the 1990s.

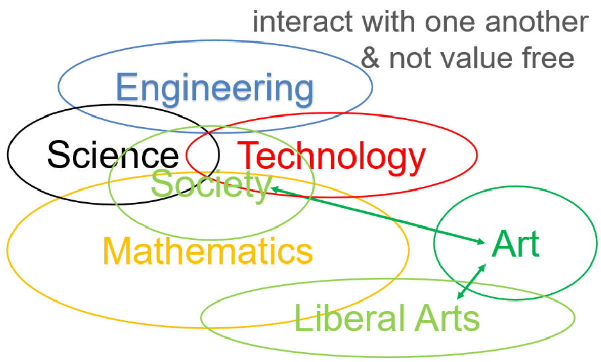

Fig. 2. STEAM education.

STEAM education

Here, STEM education that doesn't cover liberal arts and social science is skipped. Liberal arts and social science relate a lot to Society.

STEAM education is an education that relates to Science, Technology, Engineering, Art and Mathematics shown in Fig. 2. STEAM like STS has many stakeholders including scientists in every domain. Science, Technology, Engineering, Art and Mathematics interact with one another. So, they are not value free, too. Interpreting "Art" broadly, "Art" and "Society" are synonymous. STEAM education is, in a sense, almost Science, Technology, Engineering, Society and Mathematics education.

The purpose of this study is to share information about the practice of high school chemistry classes and science club, and provide ideas that may lead to your awareness of STEAM education.

Practices

The author introduces his concepts of pH changes and river water in STEAM education and then shares information on his high school science club activities and his high school teaching practices.

Concepts of pH changes and river water in STEAM education

Fig. 3. shows a part of concepts of pH changes and river water in STEAM education. Science includes chemistry [ionization, solubility and dissolution equilibrium, pH], biology [photosynthesis and respiration], geology, scientific method [to collect the sample water, analyze it, discuss data, make a report and present the findings], model experiment and simulation, etc., Technology and Engineering includes the way to use pH meters, wastewater treatment etc., Art [Society] includes environmental issues and its regulation, etc., and Mathematics includes calculations of exponents and logarithms, and so on.

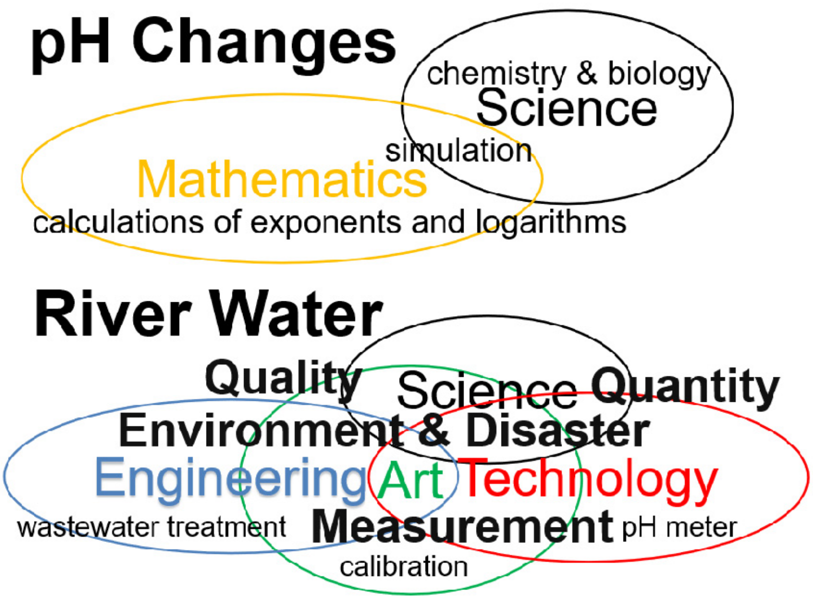

Fig. 3. Concepts of pH changes and river water in STEAM education.

High school science club activities

Survey about river water quality Fig. 4. shows the pH of the water versus the water temperature of the Funahashi River from 2014 to 2018. The line graph indicates the pH and the bar graph indicates the water temperature. In summer, the river water is almost always alkaline.

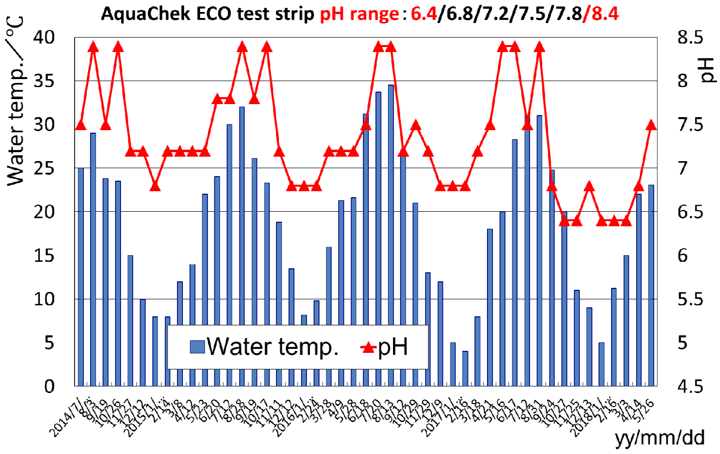

Fig. 4. pH and water temperature of the Funahashi River.

Some volunteers from the students to whom the author taught chemistry wanted to study the reasons why the river water became alkaline after school. A few of them made a science club of which the author has been the mentor for seven years. They took photosynthesis of both aquatic plants and phytoplankton in the river into consideration. The graph shows that the pH increased as the water temperature rose. An increase of the water temperature caused more active photosynthesis of the aquatic plants and phytoplankton in the river. They consumed more CO_2 dissolved in the water.

Chemical Equilibrium $CO_2 + H_2O \rightleftarrows H^+ + HCO_3^-$

This equation indicates that CO_2 reacts reversibly with water to form a solution of the weak acid, H_2CO_3 (carbonic acid). A decrease in concentration of CO_2 shifts this equilibrium to the left as this decrease effects a decrease in concentration of H^+, that is, an increase of the pH.

From these results, they concluded that the stronger photosynthesis of the plants and phytoplankton in the river caused the increase of pH in the summer.

$CO_2 + H_2O \rightleftarrows H^+ + HCO_3^-$

According to the Iwanami Rikagakujiten, pK1 = 6.35. ∴ $pK_1 = -\log K_1$, then $6.35 = -\log K_1$. Thus, $K_1 = 10^{-6.35} = 4.5 \times 10^{-7} \fallingdotseq 5 \times 10^{-7}$

If pH=5.7, then $[H^+] = 2 \times 10^{-6}$ mol/L and $[HCO_3^-] = 2 \times 10^{-6}$ mol/L, too.

$K_1 = [H^+][HCO_3^-] / [H_2CO_3] = 5 \times 10^{-7}$

$[H_2CO_3] = 2 \times 10^{-6} \times 2 \times 10^{-6} / 5 \times 10^{-7}$

Thus, $[H_2CO_3] = 8 \times 10^{-6}$ mol/L.

If $[H_2CO_3]$ decreases to 2×10^{-10} mol/L,

$[H^+][HCO_3^-] / 2 \times 10^{-10} = 5 \times 10^{-7}$

then $[H^+]$ and $[HCO_3^-]$ equals 1×10^{-8} mol/L.

Thus, the pH =8.

As a result, the pH increases to 8.0 from 5.7.

Schema 1. Simulation of pH change to 8.0 from 5.7.

Simulation They simulated the pH changes shown in Schemata 1.-2. and confirmed the pH changes. They presented the result of this study by poster at NICEST (Nippon International Chemistry Expo for Students and Teachers) 2017 Tokyo (Fig. 5.).

The team simulated the pH change of the water from the viewpoint of the equilibrium equation shown below.

$H_2CO_3 \rightleftarrows H^+ + HCO_3^-$

They calculated the dissociation constant K_1 mentioned below from data in the Iwanami Rikagakujitenn (1998).

$K_1 = [H^+][HCO_3^-] / [H_2CO_3] = 5 \times 10^{-7}$

The initial conditions are as follows:

If pH=6.7 at equilibrium, then $[H^+] = 2 \times 10^{-7}$ mol/L.

Thus, $[H_2CO_3] = 8 \times 10^{-8}$ mol/L.

Next, the plants consume CO_2 dissolved in the water.

If $[H_2CO_3]$ decreases to 2×10^{-11} mol/L, then $[H^+]$ and $[HCO_3^-]$ equal $1 \times 10^{-8.5}$ mol/L. Thus, the pH = 8.5.

As a result, the pH increases to 8.5 from 6.7.

Schema 2. Simulation of pH change to 8.5 from 6.7.

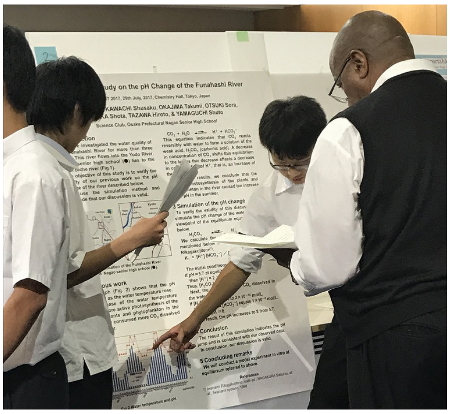

Fig. 5. Poster presentation in English at Chemistry Hall.

Fig. 6. A model experiment of the pH changes by photosynthesis.

Model experiment Some model experiments were conducted (one of them shown in Fig. 6.). Science club members measured the pH and dissolved oxygen (DO) of the water in both the beaker (water only) and the desiccator (water with aquatic plants) under the sunshine in the spring morning. The result of this experiment is shown in Fig. 7.

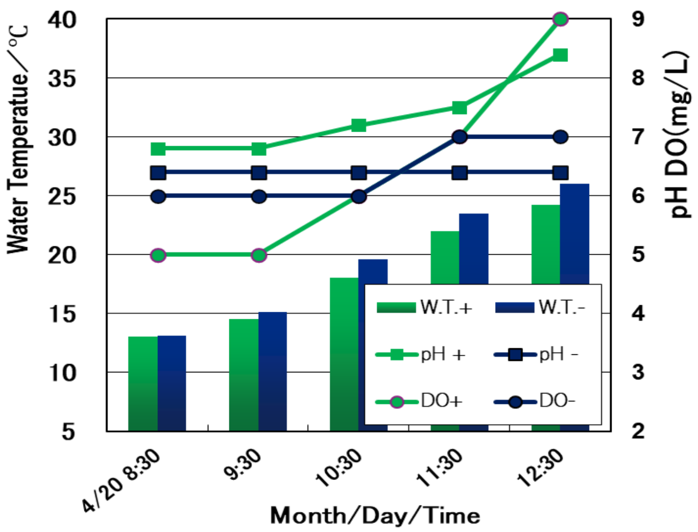

Fig. 7. The changes of water temperature, DO and pH of the water with plants (+) and water only (-).

As the water temperature rose, the pH+ (with plants) increased to 8.4 from 6.8 and also the DO+ increased to 9 from 5 remarkably, but the pH- (water only) did not change and the DO- increased a little to 7 from 6. These indicate that more active photosynthesis of the plants by higher water temperature decreased CO2 and increased O2 in the water. That raised both the pH+ and DO+. Science club members presented the findings by poster in Japanese at Kyoto University Academic Day 2019 (http://hdl.handle.net/2433/244419, in Japanese).

pH and RpH of the river water Tab. shows pH and RpH of the Yamashina River (Fig. 8.) two or three years ago. Reserved pH (RpH) [5] is defined as the pH at which the CO2 concentration of the water is in equilibrium with that of the atmosphere [6]. Science club members stirred [aerated] the river water in the container for more than 15 minutes with a SK-632PH pH Meter (measurement accuracy: +-0.4 pH, automatic temperature compensation function) shown in Fig. 9., and then measured the water pH (RpH).

Tab. pH and RpH of the Yamashina River.

Year	2022		2023		
Month/Day (Time)	8/16 (14:25)	11/22(14:25)	2/25(11:30)	3/28(10:45)	9/5 (8:15)
pH	9.55	8.75	8.48	8.81	8.78
RpH	8.01	8.01	8.05	8.22	8.25

Fig. 8. The Yamashina River in Kyoto Prefecture.

Fig. 9. A pH meter in a yogurt container attached to some cord.

The red shape shown in Tab. indicates that discrepancy between the pH and RpH values that exceeds about +-0.8 pH. In this case, the pH and RpH values are not the same. Because the pH meter has measurement accuracy: +-0.4 pH. There is a discrepancy between the pH and RpH values, shown above.

Biological fluctuations, such as the change of balance between photosynthesis and respiration in the river, cause the discrepancy [5] [6]. Besides, the water whose value of pH is higher than about 9 is weak alkaline. It may become an environmental risk not only for aquatic life but also for the human race. Science club members presented the new findings about pH and RpH of the Yodo River system by poster in English at the 10th NICE Conference 2025 Yamagata. They could improve their self-esteem and competences.

High school teaching practices

Water quality test from the "Acid and Base" unit of Grade 2's Basic Chemistry course Fig. 10. shows an experiment of high school chemistry in the 2000s. The students checked river water qualities by AquaChek ECO test strips. They were surprised at the alkaline river water and said, "Why is the river water alkaline?"

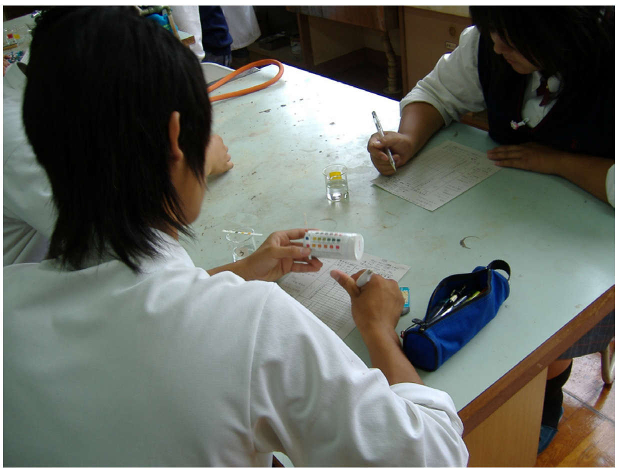

Fig. 10. A water quality test from the "Acid and Base" unit of Grade 2's Basic Chemistry course.

Ionization equilibrium of weak acid in Grade 3's Chemistry course In the unit of ionization equilibrium of weak acid and base of chemistry class, the author always showed the Fig. 4. and the students were surprised at the fact that the river water was sometimes alkaline. He asked, "Why is the river water alkaline?" They started to discuss with each other.

A few minutes later, he showed the Figs. 6.-7. and described the Schemata 1.-2. of the science club study mentioned before. The students were amazed at the pH change mechanism including ionization equilibrium of weak acid by photosynthesis. Most of them understood the mechanism with wonder and satisfaction.

Conclusion

In the past, the author mentioned "the water quality of rivers" as a teaching material [9] - [11]. This time, he has reviewed his practices relating to "the water quality of rivers".

Considering the results of his practices described above, he concludes the following:
Firstly, the teaching material "pH changes of the river water" is valuable for STEAM education, because it contains many concepts in every STEAM domain.

Secondly, the material arouses high school students' interest. This is because it is a curiosity for not only the students, but also the masses. People believe that river waters are neutral and they are sure that the waters are not alkaline or acidic.

Thirdly, the mechanism of the pH change including ionization equilibrium of weak acid by photosynthesis is amazing for the students. To learn "chemical equilibrium" in chemistry class, it is easy to understand the mechanism above. He saw many students understand the mechanism with wonder and satisfaction.

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References

[1] Shiokawa, T.; et al., *Proceedings of 17th Japan Society for Science Education Annual Meeting*, 135-136 (1993, in Japanese).
[2] Shiokawa, T.; et al., *Proceedings of 18th Japan Society for Science Education Annual Meeting*, 81-82 (1994, in Japanese).
[3] Hirai, T.; et al., *ibid*., 83-84 (in Japanese).
[4] Hirai, T., *Kagaku to Kyoiku*, 43(1), 23-26 (1995, in Japanese).
[5] Yasutomi, R.; et al. *Uo to Mizu*, 49 (1), 13-22 (2012, in Japanese).
[6] Yamanouchi, T.; et al., *Hozenseitaigaku Kenkyu* (*Japanese J. Conserv. Ecol*.), 16, 169-179 (2011, in Japanese).
[7] Neal, C.; et al., 210/211, Sci. *Total. Environ*., 205-217 (1998).
[8] Neal, C.; et al., 282-283, ibid., 205-231 (2002).
[9] Hirai, T., Chem. Edu. J., 17, No. 17-205, 1-9 (2017).
[10] Hirai, T., Proceedings of 8th NICE Conference, 28-31 (2019).
[11] Hirai, T., ibid, 176-178 (2019).