The Aspects and Changes of Students' Environmental Science Agency in the Action-oriented Science Education Program Using Physical Computing and Internet of Things

Seok-Hyun Ga, Hyun-Jung Cha, Chan-Jong Kim

1 Gwanak-gu, Gwanak-ro, Seoul, Korea

chajokim@snu.ac.kr

Abstract. We studied the aspect and change of students' environmental science agency (ESA) in an action-oriented science education program adapting Do it yourself Measurement Devices using Physical Computing and Internet of Things (DIY-MD). This program has two characteristics: first, it uses DIY-MD in the process of scientific inquiry. DIY-MD helps students obtain the data they need to carry out scientific inquiries. Second, this program includes the step of social action. Students are not only cultivating content knowledge and practical knowledge through class, but also skills of social action based on them. Through this, students develop action competence that can lead to positive societal changes. The researcher developed an action-oriented science education program using DIY-MD for eight weeks (24 sessions) and applied it to undergraduate students. The program consists of four weeks (12 sessions) of learning DIY-MD utilization and four weeks (12 sessions) of the student-led project for social action. The researcher investigated students' agency in the class using the ESA lens through the preliminary interview on the students' background, the post-interview on the project activities of the students in the class, the researcher's field notes. For the credibility of the results, two researchers analysed the data and compared them. As the results, the researcher found five points: first, at the beginning of the project, it started with a layman level of knowledge but gradually explored expertise as needed as the project activities progressed. Second, as the project progressed, students had been perceived the topic as their problem. Third, students recognized himself as an actor of environmental problems by securing his own meaningful data. Fourth, Students first took action for societal changes using science. Fifth, students have the ability to participate in environmental problems using DIY-MD.

Abbreviations

• AOSE	Action-oriented Science Education
• DIY-MD	Do it yourself Measurement Device using Physical Computing and IoT
• ESA	Environmental Science Agency
• IoT	Internet of Things
• PAL-XFEL	Pohang Accelerator Laboratory X-ray Free-electron Laser
• S&T	Science and Technology
• SSI	Socioscientific Issues
• UV	Ultraviolet ray
• UVI	UV Index

1. Introduction

Civic participation in the SSI is emerging as a reaction to technocracy [1]. The expertise required for participation is not limited to science. It is also associated with social and economic aspects and the local community contexts. Even if someone is an S&T expert, their expertise is limited to some areas. S&T experts are also novice about the local community, but ordinary citizens who live in that place for a long time are experts about their local community [2]. However, there is a growing concern about citizen's lack of expertise about S&T [3–7]. Since SSIs include complex science-related content, it is necessary to be competent with scientific content knowledge, scientific inquiry skills, science communication, and social action. Therefore, for drawing citizens' meaningful participation, science education makes them competent for civic participation.

2. Theoretical Background

2.1. Action-oriented Science Education (AOSE)

In AOSE, a student is not just a citizen who forms a future society but a citizen who lives today [8]. As an independent actor, a student develops the ability to take action by becoming informed and empowered citizens [9,10]. Students have the right to participate in democratic decision-making in civil society as citizens living today [8], so they should not simply engage in SSIs in an educational context but take action in real society.

Canada's STEPWISE is a representative example of AOSE. STEPWISE stands for 'Science and Technology Education Promotion Wellbeing for Individuals, Societies and Environments' and analyzes the irrationality of science and technology caused by neoliberalism and capitalism from various perspectives and realizes social justice. Through this program, student cultivates the ability to take action for a better society [11]. In this program, the student conducts scientific research related to the specific problems of their interest and takes actions to create a better society based on them. The program consists of two main steps. The first step is the RiNA Apprenticeships. RiNA stands for "Research-informed & Negotiated Action," in which students conduct scientific research and take action with the help of their teachers. Through this process, students will reflect their experience and develop expertise for independent RiNA projects. The next step is the student's RiNA projects. In this course, students will have independent status as actors by performing RiNA without the help of teachers [11].

2.2. Environmental Science Agency

In the field of science education, interest in 'agency' is increasing [12]. Teachers and students are the prominent actors in education, and their actions affect the structural changes of schools and society [13]. The view of agency has broadened the perspective of researchers in pedagogical studies to look at the phenomenon. As constructivism has become more common, students are widely accepted as the subject of knowledge construction. However, students are still passive learners and have not been regarded as active actors who change the school or social structure. However, as students are seen through the lens of agency, they are not just passive beings who have to adapt to school culture and norms but active beings who actively reproduce and change school culture and norms.

The study of agency in science education has been widely conducted. Biddulph studied the students' curriculum agency in the curriculum development project called 'Young Peoples' Geographies (YPG). In YGP, students use their voices and common sense to influence their curriculum, which is a part of the school, which the researcher called curriculum agency [14]. Edward conducted a literature study on 'relational agency.' Relational agency refers to "a capacity to work with others to expand the object that one is working on and trying to transform by recognizing and accessing the resources that others bring to bear as they interpret and respond to the object." [15] Also, Basu et al. [16], Calabrese Barton & Tan [13], Schenkel & Calabrese Barton [17] studied 'critical science agency' which focused on the action against social injustice. Science agency refers to the capacity to draw scientific knowledge for taking action [17]. The word "critical" explicitly reveals the political perspectives of researchers to connect the concept of justice to science agency [17]. In this perspective, Critical Science Agency (CSA) requires another kind of competence that can handle social injustice beyond simply acquiring scientific content knowledge and practical knowledge [18]. In addition, beyond the existing scientific literacy perspective of 'what it should be,' the CSA makes students participate in the world and make changes. Education reflecting CSA perspectives can make minority students under injustice in school become actors who can change their school and community using science.

The ESA is stemmed from the critical science agency of Basu & Calabrese Barton [20,21]. ESA reflects the context of environmental conservation and science, which means the capacity to influence the surrounding world for the environment. Students who participate in civic science programs in the community exert ESA through developing their inquiry skills, using them to conduct inquiries, and feeling that they can preserve the environment [22]. To be a legitimate actor who exerts ESA, students should not only understand environmental issues and learn how to deal with the tools to solve problems but also assimilating the values, goals, and norms of the community associated with environmental issues [23].

3. Research Question

In this study, we developed an AOSE program to help students have the ability to participate in decision-making on SSIs as citizens and applied it to undergraduate students. The feature of this program is that it used DIY-MD to support students' scientific inquiry. DIY-MD helps them secure more professional scientific evidence by complementing the lack of measurement tools that ordinary citizens did not have, unlike science and technology experts [24]. The aspects and changes of ESA of students were examined, and the effects of DIY-MD on ESA were examined. The research questions of this study are as follows.

- How did aspects and changes of students' ESA appear in the AOSE program using DIY-MD?

4. Methodology

For identifying aspects and changes of students' ESA, descriptive-interpretive qualitative research was conducted [25]. We applied the developed AOSE program to undergraduate students in the College of Education. Five students participated in this program, but three of them were investigated. One student stopped participation early, and the other was excluded from the analysis due to personal reasons.

4.1. Instructional Design

In this program, students explore environmental issues around us, design and conduct scientific inquiries using DIY-MD. Based on the result, students make an action plan and take action for making a better society. A characteristic part of this program is that students use DIY-MD in the process of conducting scientific inquiry. Students collect scientific evidence using this device to support their claims.

The program consists of 8 weeks (24 sessions), and the one session is 50 minutes (Table 1). This program is divided into two parts. In Part 1, students learned how to make DIY-MD and use IoT platforms. The main purpose of this program is not to develop students' coding skills or computational thinking skills, so it focuses on having the practical ability to develop DIY-MD based on examples rather than detailed grammar or algorithms required for programming. In the first and second weeks, students learned the essentials of Arduino. In the third week, they learned how to deal with the thermo-humidity sensor (DHT11) connecting to Arduino, transmit data to the IoT platform, and analyze data stored in the platform. In the fourth week, based on what they learned in the third week, students practiced making DIY-MD using various sensors. Also, they were informed about the projects they would carry out in Part 2.

In Part 2, students selected the suspected environmental problems, explored the problems using DIY-MD, and take action to solve the problems. In the fifth week, each student presented their project plan, provided feedback to each other, and they had time to revise their plan based on feedback. After that, from the 6th week, the inquiry was carried out, the data obtained through the inquiry were analyzed to draw implications, and social practice was carried out based on this.

Table 1. Contents of AOSE Program

Weeks (Sessions)		Contents	Type
Part 1	1(1~3)	• What is Physical Computing and Internet of Things? • Principle of electrical signal (digital and analog signal) • Digital input/output (blinking LED, resistance and breadboard, serial monitor)	Group
	2(4~6)	• Analog input/output (variable resistance, photo resistor, thermometer) • Coding via Arduino library (ultrasonic Sensor, servo motor) • Various application of Arduino (including LCD module)	Group
	3(7~9)	• Sensors and actuators (Including DHT11 sensor) • Connecting to the Internet using Wi-Fi module (ESP-01) • Analyzing data stored in the IoT Platform	Group
	4(10~12)	• Making DIY-MD for their interest sensors • Noticed the project which will be done in Part 2 • Introducing example of projects all over the world	Group
Part 2	5(13~15)	• Sharing students' research plan • Revising research plan • Mutual feedback	Group
	6~8(16~24)	• Making DIY-MD for their inquiry • Collecting and Analyzing Data • Planning for Social Action • Taking Action	Individual

4.2. Participants

Five second or third-grade undergraduate students consisted of one woman and four men participated in this study. They're all majoring in earth science education. In the first semester of 2020, these students took the "Earth Science Teaching Theory [地球科學教育論]." Students studied STS, SSI education, and AOSE in one week of the 15 weeks of classes. In that week, researchers informed students of recruiting research participants about an AOSE program. Because classes were conducted online due to the COVID-19 pandemic, participation recruiting was also conducted online.

4.2.1. Student Y

Student Y is a sophomore majoring in earth science education. He graduated from a public high school in a small city. Recently, He recognized computer programming as a trend, so he thought he should learn computer programming, but didn't have a chance. While he was feeling like that, he heard about this program and decided to participate. He had decided to major in earth science education because he was interested in math, science, and pedagogy. However, after graduation, he plans to go to graduate school in natural science instead of being a teacher.

The project topic of Student Y was 'the harmfulness of PAL-XFEL.' Because PAL-XFEL was around his home, this topic was easily imagined. However, Student Y was not worried about the harmfulness of the accelerator. Student Y made DIY-MD connected Gauger counter sensor that measures radioactivity levels around the accelerator (Figure 1). Since the accelerator is not continuously operated throughout the year, the level of radiation should be measured at the operating stage. The measured radiation intensity was not significantly different from the region far from the accelerator, which concluded that there was no need to worry about the emission of harmful radiation from the accelerator. Student Y thought social action to inform safety is not meaningful because there is little concern about the accelerator in the local community. So, he told the researchers that he would not carry out social action.

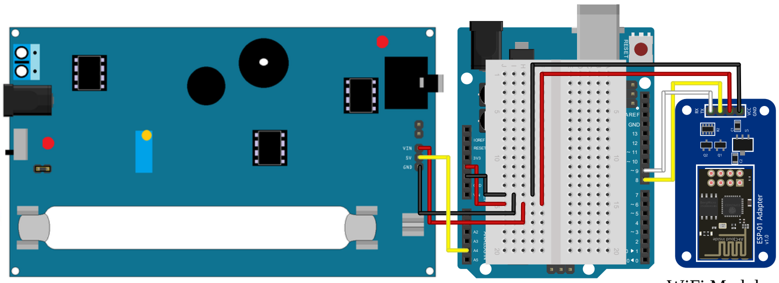

Figure 1. Fritzing Diagram of Student Y's Device

4.2.2. Student J

Student J is a sophomore majoring in earth science education. He graduated from a public high school in a provincial metropolitan city (廣域市). He said he participated in the program "to learn something to live in the future as a teacher," such as computer programming. However, he has no plan to become a teacher. He thought that he should have the qualifications as a future teacher as just students in a college of education.

The project topic of Student J was "Danger of Indoor UV rays," and he planned to measure ultraviolet rays in places where people stay for a long time in university. Student J hypothesized that people sitting in classroom window seats or sunny lounge seats would be severely exposed to ultraviolet light because strong sunlight through windows contains strong ultraviolet light. He looked for a suitable sensor to measure ultraviolet light. In this experiment, it was important to obtain an ultraviolet index (UVI) that could determine the harmfulness of ultraviolet rays in real life, rather than measuring the exact intensity of ultraviolet rays. Student J found CJMCU-S12SD as a suitable sensor and made DIY-MD using it (Figure 2).

Student J first measured the indoor and outdoor UV rays of the building where his department was located. He measured the sunny exterior, shaded exterior, sunny interior when windows were opened, and sunny interior when windows were closed. As a result, UVI was high in the following order:

Sunny exterior > Sunny interior when opened > Shade exterior > Sunny interior when closed

According to the study, windows played a crucial role in blocking UV rays entering the room, and the apparent brightness did not mean that the UVI is high. To check that windows in other buildings are also barred from ultraviolet rays, he moved to other buildings, performed the same experiment, and obtained similar results. Encouraged by exciting research results, he also experimented on the bus window and concluded that the bus window was also safe. He saw the news articles that fluorescent lamps emit ultraviolet rays through additional internet searches, measured ultraviolet rays emitted from fluorescent lights and LEDs, and confirmed that ultraviolet rays were not released.

Through this experiment, he found that ultraviolet light drastically weakens as it penetrates the window, and that a considerable amount of ultraviolet light enters the room if the window is open, even if the direct sunlight is not shining. This result was different from conventional thinking: the stronger the apparent brightness, the more exposed the ultraviolet rays. Student J thought he should let others know about it and posted his research in the form of card news on Facebook (Figure 3).

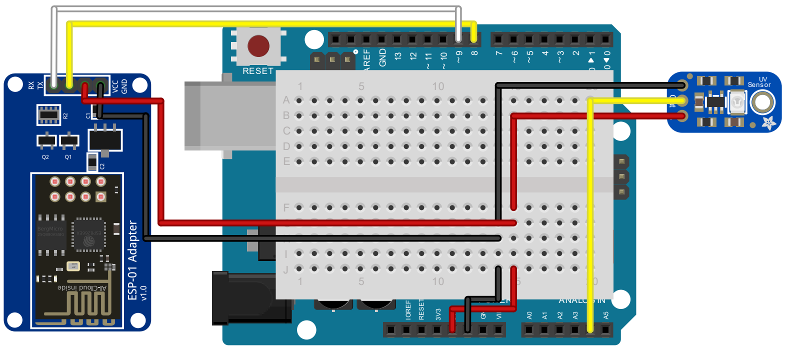

Figure 2. Fritzing Diagram of Student J's Device

Figure 3. Uploaded Post in Facebook by Student J

4.2.3. Student P

Student P is a sophomore majoring in earth science education. She graduated from a public high school in a small city. When she heard about this program, she felt that physical computing and IoT are very brand-new technology, and the education program, including social action, is brand-new education. She decided to participate in this program because she thought it was different from the current school education and thought it was a good opportunity to learn new technology. In addition, as the assessment rate of Comprehensive School Report (CSR, 學生簿) in university entrance examinations has increased in recent years, extra-curricular activities such as student R&E are considered important. She thought that the experiment using Arduino could be used meaningfully when teaching student R&E as a teacher in the future.

Student P chose 'Street Secondhand Smoking' as the project topic. Through the project, she wanted to reveal that cigarette smoke from smoking areas is causing people on the street to be exposed to second-hand smoke and suggest installing smoking booths near smoking areas. She made DIY-MD using the carbon monoxide sensor MQ-7 and the smoke sensor MQ-2 to detect cigarette smoke (Figure 4).

Student P conducted research on smoking areas in his university. Since the school had not designated smoking areas, she found the most likely place for students to suffer from second-hand smoke and decided to research smoking areas near the Central Library. She installed three measuring devices around the smoking area. Device A was placed closest to the smoking area, and the Device B and C were located somewhat away from the smoking area and adjacent to the walkway (Figure 5). By measuring how much smoke detected in A is caught in B and C, she tried to figure out how much cigarette smoke in the smoking area (A) affects the walkway (B, C). However, she had difficulty making meaningful interpretations from the data. Device A in the smoking area continued to measure high values at dawn when there were no smokers. Therefore, it was impossible to interpret the collected data, so she ended the project without going to the social action.

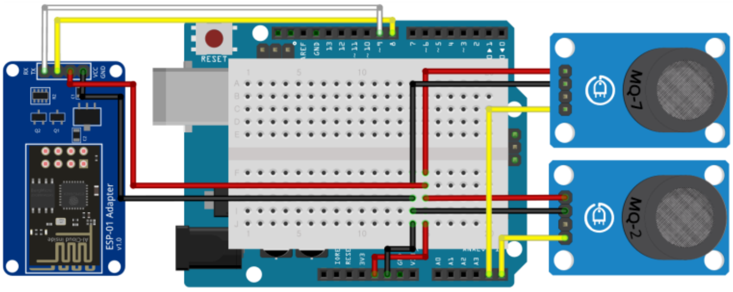

Figure 4. Fritzing Diagram of Student P's Device

Figure 5. Installed Location of Devices

4.3. Data Collection

Various kinds of data were collected. Online surveys and pre-interviews were conducted to understand the student's background and motivation to participate, and post-interviews were undertaken to understand the student's experience during the class. The pre-interview was conducted based on focused questions based on online surveys, and the post-interview was conducted by focused questions for the purpose of research. During the study, the instructor wrote the research notes by date. In the instructor's research note, everything that came to mind about the class was written as much as possible, including the contents of the course, the thoughts of the class, special comments about the student, future plans, and the thinking about the program improvement.

4.4. Data Analysis

The researchers modified the ESA framework used in the study of Ballard et al. [22] and Harris & Ballard [26] and used it to analyze the collected data. ESA is stemmed from Basu & Calabrese Barton [20,21] 's Critical Science Agency (CSA). The reason for the modification was that Ballard et al. [22] only briefly stated the concept of each component but did not provide specific examples. Hence, it was somewhat ambiguous to use as a framework for analyzing data. The framework of Harris & Ballard provides detailed examples of each component of agency detail. Still, it is based on data collected from that study and therefore is limited in other contexts.

The modified framework was derived by the following process (Figure 6). First, we created an initial model based on the two prior studies, which attempted to analyze the data for three student cases. When faced with the limitations of the framework in the data analysis process, the framework was modified. And we analyzed the data again with the revised framework. This modification process was repeated several times and cross-validated with one Ph.D. researcher. The final framework is shown in Table 2.

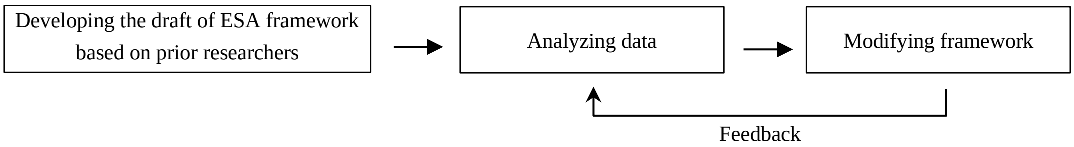

Figure 6. Process of developing ESA framework

5. Result

Through data analysis, the researcher was able to classify the student's ESA into five categories, which are shown in [Table 2].

5.1. Understanding content knowledge related to environmental science

At the start of the project, students focused on content knowledge of environmental science at the level of ordinary people, such as finding mass media (newspapers and blogs) on various environmental issues. Rather than trying to understand the scientific principles of environmental issues, they focused on looking at controversies among the public. However, as the project progressed, the students became more and more aware of the need for expertise. Students began to explore the expertise of environmental issues.

5.1.1. Searching media (newspapers, blogs) for environmental science information

While selecting the topic, Student Y looked at experts' views on PAL-XFEL through Internet news. He thought it was meaningful to check the harmfulness of the accelerator because he found conflicting opinions among experts. However, he just read the news at a general level and did not reach a deeper level of expertise.

Student J was also searching for news articles on the Internet. He came across the "Danger of Indoor UV rays issue" and chose it as a project topic. He looked up more articles to get more information about this issue and found that several media dealt with it. However, he focused on controversies among the public and did not look scientifically at how ultraviolet light is harmful to the human body.

5.1.2. Exploring expert-level scientific knowledge

To detect the harmfulness of the radiation accelerator, Student Y needed to understand what harmful substances or energy the radiation accelerator emits. Student Y began to look for the Internet on how the accelerator work and found that X-rays can be a potential risk. To detect X-rays, he selected the Geiger-Muller counter as a sensor detecting X-rays.

However, Student J did not need to find more expertise in the whole procedures of his project. The fact that UV rays come from the sun and affect humans is common sense. Also, the UVI is a simple number that easily graded UV rays' harmfulness on humans. Even in the process of selecting sensors, it did not need professional knowledge. CJMCU-S12SD measures light in the range of 240-370 nm and thus best detects UVB series of light harmful to the human body. However, he chose the sensor not because of these features but because the example code for CJMCU-S12SD was readily available over the Internet.

Student P had difficulty calibrating sensors while making DIY-MD. When she tested the operation of his devices, the values of the MQ-7 and MQ-2 sensors observed on the three devices are significantly different. She looked for relevant knowledge to read the sensor's datasheet to solve this problem.

> Researcher: MQ sensor not working well. I should support calibration for the MQ sensor. I should meet Student P and watch the datasheet together. (Researcher's Research Diary)

Table 1. Aspects and Changes of Student's ESA

Components	Category	Aspects*	Changes
Understanding	• Understanding content knowledge related to environmental science	• Searching media (newspapers, blogs) for environmental science information (Y, J) • Exploring expert-level scientific knowledge (Y, P)	• At the beginning of the project, it started with a layman level of knowledge but gradually explored expertise as needed as the project activities progressed.
Positioning	• Recognizing environmental problems as their own	• At the beginning of the project, there were students who thought their topic was their problem (P), and others who weren't (Y, J) • Through the project implementation, Students perceive this topic as an important issue that can affect them (J, P)	• As the project progressed, students had been perceived the topic as their problem.
	• Recognizing oneself as an actor in solving environmental problems	• At the beginning of the project, students don't think themselves as an actor to solve problems (Y, J, P) • Obtaining meaningful data has a significant impact on recognizing themselves as an actor of solving problems (Y, J, P) • Through the project experiment, the student recognized that he could make a change using DIY-MD (J)	• Students recognized himself as an actor of environmental problems by securing his own meaningful data.
Extensionality	• Sharing their research results with others	• Sharing the results of the experiment with the people in this class and receive feedback (J) • Creating and posting card news on Facebook to inform the public (J) • Student J shared his card news when the indoor UV issue was mentioned in the KakaoTalk chat room composed of middle school friends (J)	• Students first took action for societal changes using science.
	• Extending their experience to a new environment/context	• Developing the ability to solve new environmental problems using DIY-MD based on project experience (Y, J, P)	• Students have the ability to participate in environmental problems using DIY-MD.

* Y: Student Y, J: Student J, P: Student P

5.2. Recognizing environmental problems as their own

At the start of the project, some students considered their topics as their problems (Student Y, J) and others who did not (Student P). However, students who did not think of it as their problem gradually recognized it as a 'their' problem after selecting it as a project topic and looking into it in depth.

5.2.1. At the beginning of the project, some students thought their topic was their problem, but others who weren't

At the beginning of the project, students Y and J did not recognize their topic as their problem. Student Y was a resident of the area where the accelerator is located before entering university, and his family still lives there. However, the harmfulness of this accelerator was not usually felt strongly problematic.

> Student Y: The radiation accelerator was built in the university. The university had many students and researchers so that it would have been built safely. (Student Y Post Interview)

Student J also didn't think of 'Danger of Indoor UV rays' as 'his problem' because he was insensitive enough to not apply sunscreen even in the summer.

> Researcher: How did you choose this topic?
> Student J: I found this topic while searching the Internet.
> Researcher: Have you always been interested in ultraviolet light?
> Student J: Honestly, I was only interested in fine dust and not UV rays before this experiment.
> (J's post-interview)

Unlike Students Y and J, Student P thought the topic is 'her problem.' She P lived in small-sized cities when he was in middle and high school, and he was rarely exposed to second-hand smoke.

> Student P: I heard there were schools with students who smoke, but no one in my school.
> Researcher: No one smokes? Girls' school?
> Student P: Yes, it's a girls' high school, but after moving to Seoul, I found many people smoking on the street.
> Researcher: I think many people are smoking on the street in ○○ (Student P's hometown).
> Student P: No, there was no smoker in my school route.
> (Student P Post Interview)

However, She came to Seoul and was surprised that so many people smoked on the street. She felt unpleasant whenever the smell of cigarettes was coming. She wanted a smoking booth installed in the university, but it was only the moment she was exposed to the smell of cigarettes, but she quickly forgot.

5.2.2. Through the project implementation, Students perceive this topic as an important issue that can affect them

Students J and P did not consider the project's theme as 'their problem' at first, but gradually became aware of it as an important issue and began to consider it as 'their problem.'

After selecting the topic, J found out that many people were more interested in indoor UV than he thought while searching for articles on the Internet. He gradually recognized it as an important issue for his community and him.

> Researcher: Did you want to solve this problem?
> Student J: After searching for indoor UV issues, I found out that this could be quite serious, so I started to examine its harmfulness.
> (Student J Post Interview)

After selecting the topic, Student P looked again at the smoking area of the university to design the experiment. In her university, the smoking area was not designated but was recognized conventionally. She looked at where these conventional smoking areas were located in order to find the right places to conduct her experiment. She realized that more people were smoking in more areas than she thought and could affect the passersby, making him feel serious about the problem.

> Researcher: Has there been any change in attitude after selecting the topic?
> Student P: I didn't think this was a big problem for me, but as I'm going to take a closer look at this topic, I thought it was really serious. (Student P Post Interview)

5.3. Recognizing oneself as an actor in solving environmental problems

At the beginning of the project, none of the three students thought it was a problem that they had to solve themselves. However, students' attitude toward solving environmental issues has changed depending on what data they obtained through their experiment.

5.3.1. At the beginning of the project, students don't think themselves as an actor to solve problems

Student Y believed that PAL-XFEL would not be harmful. But the belief that it would not be harmful was not based on scientific or logical evidence; he thought that he had no way of identifying the harmfulness and that there was nothing he could do but believe. Student Y did not see himself in a position to identify and solve the problems of PAL-XFEL. He positioned himself as someone who should simply believe, and he believed so.

> Researcher: Didn't you wonder if the radiation accelerator was dangerous?
> Student Y: I did, but I didn't know how to figure it out, and I just thought that I should believe.
> (Student Y Post Interview)

Since Student J did not care about ultraviolet rays before the project, he had no thought of solving the ultraviolet ray problem. He just chose it as his topic because he thought it was a good topic.

> Researcher: Why did you choose this topic??
> Student J: I wasn't interested in ultraviolet light. (⋯) I thought it would be a good topic to look at the Internet.
> (Student Y Post Interview)

For Student P, second-hand smoke was a problem he felt in this life, but he did not have the will to solve it.

> Researcher: You're just thinking more seriously than you thought?
> Student P: Yeah, but I don't want to deal with it.
> (Student P Post Interview)

5.3.2. Obtaining meaningful data has a significant impact on recognizing themselves as an actor of solving problems

In recognizing a student as an actor of problem-solving, securing meaningful data was of great importance. Student J found that the effect of indoor ultraviolet rays was insignificant, unlike what was reported in the media. Student J thought he had obtained quite meaningful data and was encouraged. He carried out additional experiments to other places that were not originally planned. And based on the results, he took action actively. At the beginning of the project, he was the only one who chose the topic he was not interested in, but he was most encouraged to perform social action. He was proud of his project.

> Student J: I think my project was meaningful in that I informed others about what I found.
> (Student J Post Interview)

On the other hand, student Y concluded from his data that there was no need to worry about the harmfulness of the accelerator and thought that he didn't need to take action to inform its safety. From the beginning, Y almost believed that the accelerator would not be harmless. Nevertheless, this topic was selected because he had a slight suspicion and wanted to confirm its safety. But after the data collection, all his little doubts disappeared, and he had no reason to do social action.

Student Y: I measured the radiation, but there was no significant difference. I think I chose a worthless subject. (Student Y Post Interview)

Student P thought the second-hand smoking problem was her problem, but she didn't think it was a problem she had to solve. However, if she could obtain data to support her claim, it would be easier to appeal to the university headquarters, so she was willing to act directly to solve the problem. But as he failed to secure data to support his arguments, his willingness to social action disappeared.

Researcher: You could ask for it, installing smoke booths, without data.
Student P: I thought it would look more credible if I had data.
(Student P Post Interview)

5.3.3. Through the project experiment, the student recognized that he could make changes using DIY-MD

Student J is not a person who actively claims his opinion to the outside world. Therefore, he has not spread his thoughts in public places, such as SNS. However, this project gave him the opportunities of sharing his own knowledge on SNS. Student J became aware that it would be possible to share and communicate the results of his scientific experiment of SSIs through SNS.

Student J: Through experiments there, I found that I could exchange my thoughts on SNS and communicate with them.
(Student J Post Interview)

5.4. Sharing their research results with others.

5.4.1. Sharing the results of the experiment with the people in this class and receive feedback

As soon as the experiment results were secured, Student J shared the experiment results in a group chat room composed of students participating in the class. Other students responded by seeing Student J's experiment results, and they thought he had achieved significant results.

5.4.2. Creating and posting card news on Facebook to inform the public

Student J decided to share the results in the form of card news on social media. He sent the contents of the card news to the instructor and asked for his opinion. The instructor introduced a graphic tool called "MiriCanvas" so that students can easily make beautiful card news. Student J used this tool to make the previously planned card news, posted it on Facebook, and interacted with some netizens (Figure 4).

5.4.3. Student J shared his card news when the indoor UV issue was mentioned in the KakaoTalk chat room composed of middle school friends.

In the KakaoTalk chat room composed of Student J's middle school friends, the indoor UV issue is mentioned, and Student J sent his card news to his friends. There was a perception in peer groups that Student J was an honor student with good academic performance, but he rarely revealed his knowledge in group chat rooms. This was the first time he had shared his knowledge with a friend.

Researcher: Have you shared this result with any other friends or family members?
Student J: My friends talked about indoor ultraviolet rays in the KakaoTalk chat room, so I sent my card news.
Researcher: Do you usually talk about science with your friends?
Student J: Not at all. I think this is the first time. (Student J Post Interview)

5.5. Extending their experience to a new environment/context

5.5.1. Developing the ability to solve new environmental problems using DIY-MD based on project experience

Students have the ability to participate in environmental problems using DIY-MD. Student J carried out social action, but students Y and P ended the project without social action. However, all three students stated that they wanted to carry out DIY-MD on another project and could create their own measuring devices for new projects.

> Researcher: Are you interested in doing another project on another topic using DIY-MD?
> Student P: I think I can do it.
> Researcher: Can you build a measuring device for new projects by yourself?
> Student P: Well, I think I can do it! I can buy the necessary parts from AliExpress and find how to code them through the Internet. (Student P Post Interview)

6. Discussion

The following four results were obtained: First, at the beginning of the project, it started with a layman level of knowledge but gradually explored expertise as needed as the project activities progressed. However, if it is not necessary during the project, they didn't look for relevant expertise. Second, as the project progressed, students had been perceived the topic as their problem. At the start of the project, some students considered their topics their problems, and others did not. However, students who did not think of it as their problem gradually recognized it as a 'their' problem after selecting it as a project topic and looking into it in depth. Third, students recognized himself as an actor of environmental problems by securing his own meaningful data. Students who have secured data that can provide socially meaningful implications regarding the project's topic carried out social practices actively. Fourth, Students first took action for societal changes using science. Fifth, students have the ability to participate in environmental problems using DIY-MD. It was not relevant to whether the project was carried out social action. Through just one activity to develop and utilize DIY-MD, students thought they could produce DIY-MD themselves and use it for other environmental problems.

The project in this program was student-centered activity, so it is difficult for instructors to predict the direction of students' project. Simple inquiry can be sufficiently prepared in advance for the procedures, problem situations, solutions, etc., but open inquiry in AOSE can vary in direction depending on the progression of inquiry. This particularity of open inquiry leaves several considerations:

First, it is a question of whether all students should carry out the social action. Among three students, only Student J carried out social action. In the case of Student Y, the level of radiation was measured through a Geiger-Muller counter where the PAL-XFEL was installed, and no significant difference was found compared to other regions. Because local residents did not worry about PAL-XFEL, he thought social action was meaningless. The instructor could not persuade him to perform social action.

Secondly, it is a question of what to do if the expected data are not obtained. Student P tried to prove her claim that cigarette smoke in smoking areas affects people walking on the road with data obtained from carbon monoxide sensors (MQ-7) and smoke sensors (MQ-2). However, it failed to secure meaninful data. The instructor recommended that social action be carried out without data, but she was not motivated enough. Because there is no data, she returned to her state before participating in the project: She thought it's her problem, but she had no will to act. The instructor needs to be prepared for how to deal with these situations when expected data is not collected.

7. Conclusion and Implication

In this study, we ran an AOSE program using DIY-MD for undergraduate students in the College of Education. We examined the changes and aspects of students' ESA. Students have acquired knowledge of environmental science issues, recognized them as their problem, and they decided to solve this problem. DIY-MD helped students measure scientific data on environmental issues, and students became more active in social action by securing meaningful data which support their claims. In addition, the students thought that they could utilize DIY-MD for solving other environmental problems, even though they had only done a project using DIY-MD once.

The study showed the possibility that AOSE programs using DIY-MD could contribute to students' transformation into active actors in environmental issues. However, it showed several limitations at the same time. Depending on what data is collected, social action of the project may not be possible, or it may not be meaningful to perform. While these situations are common in scientists' activities, various anomalous situations can pose challenges in guiding students in schools that require planned teaching at a limited time. Therefore, it is necessary to think about how we can deal with these anomalous situations.

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