Exploring the Effects of Implementing a Research-Based SSI Program on Students' Understanding of SSI and Willingness to Act

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Abstract

This study aimed to examine the effects of a research-based SSI program on fostering students' understanding of issues and their willingness to act. Twenty-five middle school students voluntarily participated in the program on the issue of artificial food additives over 6 months. The data were collected by means of interviews with the students, field notes, and students' artifacts such as SSI maps and journals. Results indicated that students' research experiences helped them widen their understanding of the issues and feel more connectedness to the issue and motivated to explore the hidden nature of the issue as they conducted their research. They found various stakeholders in the food industry and business network and discovered how individual stakeholders would be affected within the network. They also became aware of the inequality and injustice that arose in the network. In addition, their experience of executing research increased their confidence and willingness to act for resolving contentious issues.

Keywords

socioscientific issues – scientific literacy – research-based science learning – socioscientific issues instruction – science activism

1 Introduction

With the radical development of science and technology, we are facing various unexpected socioscientific issues (SSI). Science educators have claimed that students should be educated as responsible citizens who pay attention to SSIs and are willing to participate in resolving issues in their daily lives (Millar, 2006; Millar & Osborne, 1998; Zeidler et al., 2005). Beyond it, scholars such as Roth (Roth, 2003; Roth & Lee, 2004), Hodson (1999, 2003), and Bencze (2017) have suggested that citizens should be brought up to become proactive agents who carry out socio-political actions for the wellbeing of societies and environments. Responding to this emphasis, major documents and curriculum in Korea have also included the ideas of activism to solve SSIs as citizens. For instance, the Korea Foundation for the Advancement of Science and Creativity (KOFAC; 2019) published a document, entitled Korean Science Education Standards for the Next Generation (KSES), as a guideline for future science education to cultivate creative talents. It defined scientific literacy as "attitude and ability to participate and practice as a democratic citizen in solving personal and societal problems with science-related competence and knowledge" (p. 9), which addressed the ideas of "participation" in and "activism" on SSIs.

To promote responsible actions for SSIs, it is critical that students have various opportunities to examine SSIs and participate in self-directed learning processes. Those experiences help students deepen their understanding of the issues and discover what they can put into practice to solve the problems. For these reasons, some SSI programs, such as Promoting Attainment of Responsible Research and Innovation in Science Education (PARRISE) in Europe and Science and Technology Education Promoting Wellbeing for Individuals, Societies, and Environments (STEPWISE) in Canada, have provided inquiry activities or research experience in solving SSIs. For instance, the PARRISE project proposes an integrated approach, called socio-scientific inquiry-based learning (SSIBL), which emphasizes examining the complexity of SSIs using scientific and social scientific methods (e.g., simulation, modeling, and surveys; Radits et al., 2017). Students start a project with their own authentic questions on SSIs and then design and conduct experiments, perform simulations and

modeling, interview relevant stakeholders, and conduct surveys to solve SSIs. Discussions on SSIs from various perspectives and positions follow. The last step of PARRISE is to take action based on their activities (Zafrani & Yarden, 2017). Similar to PARRISE, the STEPWISE program emphasizes activism. However, it focuses more on recognizing inequality, social injustice, and capitalism embedded in science and technology development (Bencze, 2017). One of the distinctive features of STEPWISE is the Research-informed Negotiated Action (RiNA) project. The RiNA project assumes that students are able to better understand the issues and inherent nature of science and technology through their own research.

Previous literature has also reported that such research experiences contribute to fostering students' willingness to act. For example, in the study by Roth and Lee (2004), students participated in the Henderson Creek project to solve water issues in their community. Engaging in the project with the local experts and residents, they became more aware of the seriousness of water problems caused by overdevelopment and more involved in the project to propose reasonable solutions. Students in Sperling and Bencze's (2010) study also conducted self-directed investigations on the issue of waste management. Their research experiences reinforced their willingness to act. Bouillion and Gomez (2001) provided similar results. Even elementary students who participated in a project on the overflow of the contaminated Chicago River became more aware of community issues and tried to search possible actions.

These approaches resonate with Vision III of scientific literacy, which emphasize socio-political action for social justice. Sjöström and Talanquer (2014) proposed critical-reflexive vision for science education. Emphasizing the complexity of human elements in science, they claimed that students should be able to examine the various facets of science, roles of science in society, and how science is communicated inside and outside classrooms. Bencze and his colleagues (Bencze, 2017; Bencze, El Halwany, & Zouda, 2020) have suggested a more activist view, saying that students should understand power relations and dynamic networks embedded in science and the complexity of different entities within the networks (Latour, 2005) beyond mere understanding of potential harms or controversies.

Thus, in the study, we designed a research-based SSI program to promote students' understanding of issues and their willingness to take action for resolving SSIs. We set the issue of overuse of artificial food additives as an SSI context. Since the issue of artificial food additives was closely related to their personal lives, we believed that the issue could motivate students to be more immersed in learning and finding ways to take action (Kim & Lee, 2019;

Niemiec & Ryan, 2009). In the program, a group of the students collaboratively conducted their own research, from identifying research topics to proposing action plans within the context. For the investigation, we constructed research questions as follows. First, to what extent do students understand the complexity of the given SSI? Second, to what extent are students engaged in the SSI as they are conducting their own research?

2 Theoretical Background

2.1 *Research-Based Inquiry on Socioscientific Issues*
Student-led research projects on SSIs are an effective way to enhance students' autonomous motivation for learning (Shim & Lee, 2019). According to the self-determination theory (Deci & Ryan, 2000), students with autonomous motivations are likely to present high achievement and effort (Barron, 2006; Corpus, McClintic-Gilbert, & Hayenga, 2009). Many empirical studies have supported the theory that autonomous motivations can be nurtured when students find personal meanings or rationale for doing certain activities, and such motivations often lead them to be more fully engaged in the activities (Niemiec & Ryan, 2009). Since SSIs are issues that students can be personally connected to, they find personal meanings to engage in. If SSIs are situated in familiar contexts like their communities, where students are likely to feel a sense of attachment (Kim, Ko, & Lee, 2020; Kim & Lee, 2019; Semken & Freeman, 2008; Semken, Freeman, & Watts, 2009), and the sense of place plays a role as a driving force for their further engagement. Birmingham and Calabrese Barton (2014) used a term "insideness" to describe it. The sense of the place, or feeling of insideness, is usually cultivated by direct experiences (Williams & Vaske, 2003). For example, in the study of Bouillion and Gomez (2001) where students conducted their project on Chicago River overflow issues, students raised questions, participated in deeper investigations, and tried to fine solutions based on their own motivations because they found personal connection to the overflow issues.

In addition, engaging in research projects on SSIs enhances students' willingness to act. For instance, Zafrani and Yarden (2017) implemented the PARRISE project, emphasizing science-based inquiry, for high school students and found that the students developed their identities as science activists who had conviction on the issues. They explained that inquiry activities situated in SSI contexts generated students' empathy toward, care about, and sense of responsibility for SSIs. Undertaking an inquiry project initiated by

their own authentic questions, the students uncovered different facets of the issues, observed and empathized with social injustice of the suffering parties, and searched for the ways to act. Nasir and Hand (2008) introduced the term "practice-linked identity" to describe the process and explained that this identity would enhance their willingness to engage in activism.

2.2   *Examining Diverse Perspectives on Socioscientific Issues*

Perspective taking is one of the critical skills to achieve in SSI learning (Kahn & Zeidler, 2016; Kim, Mun & Lee, 2020; Newton & Zeidler, 2020). SSIs, by their nature, embrace diverse values and opinions. Since people perceive the issues differently depending on where they are situated and what they have believed or experienced, it is vital to recognize and consider diverse cognitive and emotional viewpoints of others and to have openness to them (Kahn & Zeidler, 2016). Several instructional strategies have been applied to enhance students' perspective-taking skills. Some educators (e.g., Lee et al., 2013; Dawson & Venville, 2010) have emphasized dialogical processes such as debates and argumentation for developing perspective taking. For example, Lee et al. (2013) implemented SSI programs focusing on dialogical processes (e.g., small and large group discussions) for middle school students and found it contributed positively to their perspective taking skills.

Some scholars (e.g., Bencze & Krstovic, 2017; Levinson, 2010; Wood, 1998), however, have argued that it is necessary to nurture a critical perspective on science and technology beyond understanding the various perspectives surrounding the issues. They claimed that activism could be promoted by the critical examination of why science and technology are constantly causing social and ethical problems. In other words, seeing embedded injustice, power relationships among various stakeholders, and hidden ideologies in science and technology could motivate individuals to engage in discourse and decision making on SSIs (Levinson, 2010) and, even further, to take action (Bencze, 2007). The ways individuals frame the issues affect the level of their motivation for action (Bencze & Krstovic, 2017).

Bencze and his colleagues (Bencze, 2017; Bencze, El Halwany, & Zouda, 2020) have suggested the use of actor-network theory (ANT) maps as instructional tools to scaffold the critical examination. Science and technology are not an independent entity; rather, they can be analogous to a network (Latour, 2005). Within the network, all actors, even physical environments and nonhuman species, influence each other. When examining SSIs, therefore, it is necessary to examine various stakeholders and how they relate each other and to identify the power relations and dynamics among them.

3   Methods

3.1   *Research-Based SSI Program*

Twenty-five middle school students registered in a science afterschool program voluntarily participated in the study. The school was located in Seoul, the capital city in South Korea. Most of the students were interested in math, science, engineering, and technology and planned to pursue their career paths in science or engineering fields. In designing the SSI program, we emphasized student-led research experiences initiated by their own authentic questions on the issue of food additives. The research-based SSI program followed four steps (see Table 1): (1) exploring the issue, (2) identifying research topics, (3) conducting research, and (4) proposing action plans and taking action. The steps were designed mainly based on self-determinant theory (Deci & Ryan, 2000) and literature on perspective taking in SSI education (Kahn & Zeidler, 2016). In this study, this meant that we emphasized the students' autonomous engagement, from identifying a research question to carrying out the research and proposing SSIs. We chose the issue of artificial food additives as an SSI context because most of students could freely share their experiences, without much burden, and so be personally connected to the issues. We also provided times and spaces where they carefully explored the issues using various resources and examining multiple perspectives on the issues. We adapted the strategy of ANT maps, suggested by Bencze and Krstovic (2017), to guide them to clearly see multiple stakeholders and their interrelationships. However, we introduced them as a mind-map approach, SSI maps (see Figure 1 in Findings), because terms such as "actor" and "network" in ANT would not be familiar to students. Instead, we encouraged them to think about what kinds of aspects and stakeholders (or actors) they found to be related to the issues, how they interacted with each other, and how they identified research topics from their investigation using the maps. SSI maps also helped them see the hidden ideologies or power relationships among stakeholders, as Bencze and Krstovic (2017) mentioned.

The teacher (first author) as a facilitator provided a minimum guide to help the students complete each step of the program. She formulated an atmosphere where they could actively communicate with one another and collaboratively work on their own research. Finally, the students created action plans for resolving the issues based on their research findings. The program was implemented every other Saturday for 2–4 hours over 6 months. The students made groups of three to five students each. The description of the program is shown in Table 1.

TABLE 1   Program description

Steps	Description
1. Exploring the issue	– Students were invited to examine the issue of food-additive overuse and explore the issues using internet searches and discussions in groups. – Students created SSI maps on the issue to examine diverse stakeholders and the interrelationships among them.
2. Identifying research topics	– From the SSI maps, students identified a research topic to explore and developed research proposals on the topic using various methods in social science (e.g., surveys and case studies) or natural science (e.g., experiments).
3. Conducting research	– Students conducted their research, namely, they collected data, and developed final claims with the evidence they found. They also produced group reports and made presentations.
4. Proposing action plans and taking action	– Students suggested specific action plans based on their research findings and were encouraged to enact the plans.

3.2   *Data Collection*

The primary data source included group and individual interviews with the students. We informally interviewed them in groups while they were engaging in each step of the program in order to explore their experiences and challenges. The group interviews were more retrospective so the students could look back on their progress at different steps. The questions included how they chose the research topic, what they came to know as they examined various aspects of the issues, in what ways they designed and conducted research, and what kinds of difficulties they encountered. We also conducted individual interviews with students to investigate how their understanding of science technology changed, what they learned from executing the research plans, and how their research experience affected their willingness to act. The interviews were carried out one or two times per student after the completion of research project and lasted 30–40 minutes.

Other data sources included classroom observation field notes and collection of students' artifacts produced during the program. Field notes were used

to describe how each group carried out research. Students' artifacts included ssi maps, slides for their presentations, group research reports, and individual reflective journals. ssi maps informed us which stakeholders the students identified, what aspects of the issues they examined and focused more on, and so on. Slides for their presentations and group research reports contained detailed information on their research processes. Students' reflective journals included their personal reflections on how they proceeded through each step of their research and what they felt in each step. These materials not only showed their understanding and thought processes on the issues but also were used as initiators to lead interviews with them.

3.3   *Data Analysis*

For data analysis, all interviews were transcribed. We repeatedly read all the transcripts to get an overall idea of the effects of the program. We then marked meaningful passages that related to the research questions. To see more clearly what the students learned in each step of the program, we gathered the meaningful passages in each step. By constantly discussing the meanings of the passages, we generated initial codes with a few words and phrases (Miles & Huberman, 1994); for example, awareness of the risks (e.g., cause of diseases and over-use of chemicals), seeing injustice (e.g., selling unauthorized foods, priority to make profits, and big companies vs. individuals), feeling of responsibility (e.g., doing campaigns, wanting to know more, and letting people know), and positive experiences of doing research (e.g., considering various methods, enjoyment, and obtaining skills). Then, focusing on how the students had developed awareness of the various aspects of the food additives issue and how they shaped their willingness to act through program experience, we classified codes and paragraphs into larger categories and finally worked on responding to the research question.

We also analyzed the artifacts of the students. For ssi maps, we first tried to identify major features of each map. Each map had somewhat distinctive features depending on the aspects students explored. Some groups focused more on environmental aspects, whereas some other groups targeted health, economic, or societal aspects. We then collected all the words and phrases of the maps that could be major stakeholders and categorized them (see Table 2). Stakeholders in the same categories could represent different perspectives. For example, some consumers may prefer using food chemicals for better taste, but other consumers may choose not to use them due to health concerns. Thus, categorizing stakeholders helped us understand to what extent the students could identify major actors affected by the issue (including individual people, companies, environment, animals, and non-living objects) and see

hidden ideologies or power relationships beyond understanding multiple perspectives (e.g., values, beliefs, and concerns). To increase the trustworthiness of our analysis, if necessary, we revisited diverse forms of data (e.g., interviews, field notes, and artifacts; Lincoln & Guba, 1985).

4   Findings

4.1   *Experiences of Connectedness to the Issues and Widening Students' Understanding*

Although artificial food-additive overuse is regarded as a familiar and common issue, most of the students were not very aware of the contentious nature of the issues at the beginning of the SSI program. Some initial common reactions "Why does the issue matter?" "I had never thought of such food additives issues before," and "I know there are some health issues, but are the food additives causing any social or ethical problems?" The issue itself was familiar to them, but they showed a lack of the awareness on the contentious nature of the issue and had struggled with discovering what to explore. As they constructed SSI maps as shown in Figure 1, however, the students became aware of its contentious and complex nature as well as obtaining scientific knowledge on food additives.

> There are so many problems occurring due to food additives. They are all really dangerous and scary. So I was shocked to learn about that. During the research, it was somewhat surprising to see that such things could happen in our reality, in nearby places. (Interview with S3 in Group A)

> I had known only about preservatives in terms of food additives. I did not know which was the most common additive or which was the strongest. In this project, I learned a lot from examining what's the most harmful and what's the most commonly used. I think the process itself is meaningful since I hadn't known about it even though this has been a hot issue in society for a while. I think it's nice that I get to become interested in such topic after learning about it. (Interview with S4 in Group B)

The excerpts above show that the students found personal connections to the issues. As mentioned in previous studies (e.g., Birmingham & Calabrese Barton, 2014; Shim & Lee, 2019), they opened their eyes to the issue, which "has been a hot issue in society for a while" but been rarely recognized and felt that the seriousness of the issue was "somewhat surprising." As they became more
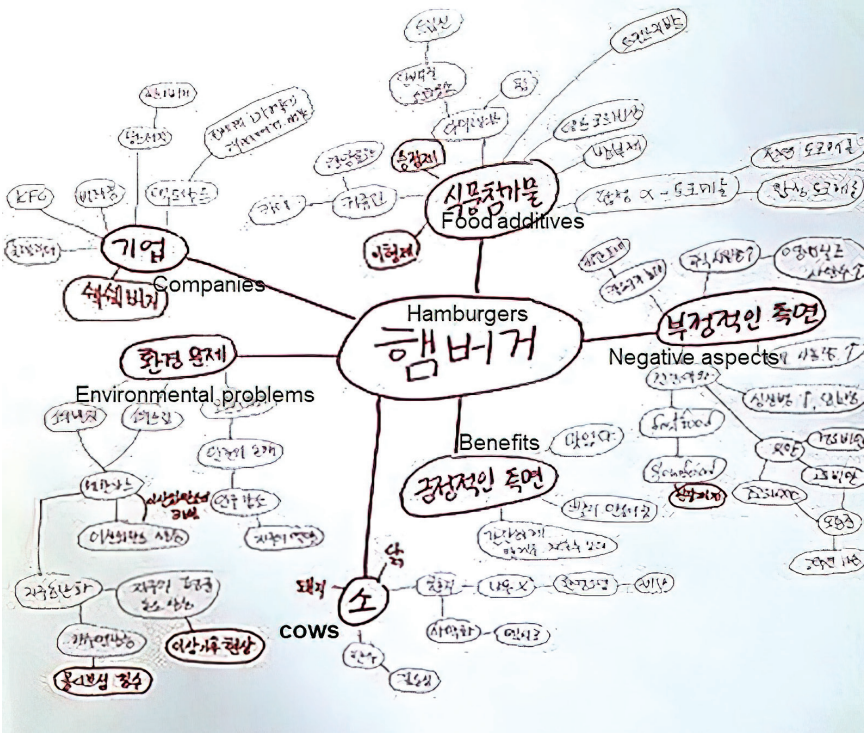
FIGURE 1　　An example of a student group's SSI map

familiar with the reality of the issue (Levrini et al., 2020), they felt more connectedness to the issue and motivated to explore the hidden nature of the issue.

In developing SSI maps, the students experienced widening in their understanding of stakeholders and potential risks of food additives. In Levrini et al. (2020), "widening" was considered as one of the positive effects of SSI instruction. They explained that despite of the complexity of the issues, students could widen their understanding and skills as they anticipated and discussed possible future scenarios within the SSI context. This effect was also found in the current study. The students placed "food additives" or the name of a food containing food additives (e.g., hamburgers) at the center of a map and started to construct the map with related words and connect them. They found that while food additives had many negative side effects on the human body, many manufacturers kept producing and selling foods containing food additives. Consumers continued to buy the foods due to the taste and convenience, even though they recognized potential risks of food additives. Table 2 shows the categories of words that the students wrote on the SSI maps.

TABLE 2   Examples of words that students wrote on the SSI maps

Categories	Examples of words
Enterprises and producers	Food companies and businesses, producers of agricultural products, scientists
Consumers	Infants and toddlers, youth, disadvantaged people
Medical practitioners	Doctors, nurses
Food products	Hamburgers, jellies and candies, instant foods, vegetables, meats
Animals and plants	Cows, grapefruit
Environment	Fields, woods, grass, climates
Chemicals	$NaNO_2$, food coloring
Economy	Expenses, profits

As they drew the maps, the students also wrote down potential dangers and risks that use of artificial food additives might cause, such as negative impact on the environment (e.g., deforestation, global warming), health concerns (e.g., diseases, overconsumption of calories), and less consideration for consumers (e.g., overuse of chemicals for more profits by manufacturers). For example, some students realized that companies grew hundreds of cows in an enormous pastureland to make hamburger patties, and the amount of methane gas emitted from cows eating crops and grass could greatly affect global warming. They also noticed inequality in capitalism, where children in developed countries frequently ate fast foods like hamburgers and large amounts of food went to waste while about 5,000 children in poor countries were dying daily due to malnutrition. Some other students found that undercooked and contaminated hamburger patties caused serious health problems in younger children, and many people suffered from obesity due to overconsumption of calories from fast foods. In addition, they noted that the nutrients contained in fast foods were unbalanced. They also criticized companies that produced hamburgers with too many food chemicals so that they could make more profits. In addition, all groups of students discovered that the food additives contained in hamburger patties include sodium polyphosphate, potassium phosphate, calcium potassium phosphate, propylene-glycol, and curcumin, which could cause detrimental side effects including damaging bone growth, gene mutation, or liver damage.

4.2   *Seeing the Complex Nature of SSIs*

As completing SSI maps and critically examining related stakeholders (or actors) from diverse perspectives, the students became aware of why food additives caused various problems. They also recognized the intricately intertwined relationships among the numerous stakeholders, including consumers, companies, animals, and the environment, and of how the stakeholders affected each other. Beyond such widened understanding, they found the existence of inequality and social injustice in the complex network (e.g., malnutrition vs. obesity, making profits vs. deforestation, and global warming), which indicated their widened epistemological understanding of science and technology. This resonates with the study of Bencze and Krstovic (2017), who highly valued the process of recognizing the hidden ideologies and power relationships embedded in science and technology because how individuals understand and frame the issues can affect the level of their motivation for action.

The research foci of the students varied depending on how they framed the issues, as shown in Table 3. Some of the groups focused more on the potential health risks whereas some others focused on the injustice of manufacturers' behaviors. Some paid attention to the consumers who were unaware of the dangers of food additives and prioritized the taste or convenience of foods. For instance, Group A and Group E brought up the issue of the low quality and imbalance of nutrition in hamburgers. They assumed that companies were likely to use more artificial food additives and lower quality of ingredients to increase their profit. Group B chose sodium nitrite ($NaNO_2$) as a topic. They paid attention to the lack of consumers' awareness of the potential health risks of sodium nitrite, one of the most commonly used chemicals, and conducted a science experiment to show them how to reduce its consumption from hams and beef jerkies. Group C focused on unauthorized food additives and their negative effects on health. They criticized its manufacturers who pursued greater profits and did not sufficiently consider their potential dangers. Last, Group D pointed out the overuse of food additives as preservatives, which could affect health.

As shown in Table 3, it is noticeable that the students chose to look at the topics from various angles. When drawing the SSI maps, they normally started with the names of chemicals. However, their focus had expanded and was not limited to scientific aspects. Some of them became more interested in the injustice surrounding the issues. For example, students in Group A and Group E were intrigued by the ingredients and nutrition of hamburger patties. They questioned the appropriateness of the hamburger price. Although the students could not accurately calculate the cost reduction from negotiation via mass production, sales, and distribution, they discussed whether the

TABLE 3   SSI research topics selected by groups

Group	Research topics	Research activities
A	Exploring the abnormal price of hamburgers	– In order to explore appropriateness of the price of hamburgers currently served in fast-food restaurants, students examined the nutrient factors and prices of hamburger ingredients. Survey on citizen's perceptions of hamburger price and ingredients' nutrition
B	Exploring ways to reduce consumption of sodium nitrite ($NaNO_2$)	– In order to detect sodium nitrite ($NaNO_2$) contained in currently merchandized processed meat (ham, beef jerky, etc.), variables (e.g., time to soak, water temperature) were set to carry out extraction. Solutions are suggested to reduce consumption of $NaNO_2$ based on experiment results.
C	Surveying awareness of unauthorized food additives	– A Google Survey was constructed to examine people's understanding of food additives that are unauthorized by the FDA. Practical solutions are suggested to improve understanding after analyzing survey results
D	Exploring the potential of grapefruit extract as a natural preservative	– Using grapefruit extract, known to have a preservative effect among various natural substances, students planned an experiment to see if it had an actual food preservation effect. After putting grapefruit extract into rice and bread and observing the change, students checked its effect as a preservative.
E	Examining the quality of ingredients in hamburgers and their effect on health	– Students assumed companies might use low-quality ingredients or food additives in hamburgers for the purpose of seeking profits. After examining the ingredients of several brands of hamburgers, students studied their effect on people's health.

price was reasonable given the ingredients of hamburgers. Compared to the inflation rate of the ingredients over the past several years, the rate of increase in hamburger prices at fast-food restaurants has not been high. The students reasoned that the quality and nutrition of ingredients for the hamburgers were inevitably low because companies always decide what to put in for a profit.

> Our research started with hamburger prices. For example, the basic hamburger from Brand A.… We simply calculated the price of the ingredients. A single bun costs 300 KRW, and 300 KRW for 20 g of lettuce, 5 KRW for 10 g of mayo, 10 KRW for steak sauce, and 1,500 KRW for a commercialized patty. We added it all up and it turned out to be 2,115 KRW while the hamburger's price is 3,500 KRW. Companies are always pursuing more profit, aren't they? But the hamburger price was rather cheaper than we expected. So, we got curious. Is it because they use a lot of artificial seasonings and additives to make it taste better or is it because they use the cheapest meat, sauce, and buns? (From Group A presentation)

As completing the maps, the students came to realize that companies used food additives to reduce the costs of hamburgers and that these could produce potential harm to human health. Students in Group E also paid attention to the fact that hamburger prices were relative cheap compared to other fast foods such as fried chicken and pizza. Searching the nutrition facts of hamburgers on the internet, they found not only that hamburgers could lead to imbalances in nutrition but also that food additives could cause serious diseases including damage to organs, genes, and the brain that could sometimes even be fatal.

> Pizza and fried chicken often cost more than 20,000 KRW. Compared to that, hamburgers do not cost over 10,000 KRW even when you order a whole set. I think there are reasonable causes for that price. As low as their prices get, ingredients in them must be low quality and/or we can't determine where they come from … You never know what might be in there…. So, considering their effect on our health, I questioned whether they were really "cheap." (Interview from Group E)

Similarly, students in Group C realized that there were loopholes in the regulations for the food additives and some manufacturers misused these loopholes. They found that some food additives had different acceptance standards in different countries. Some food additives were forbidden in foreign countries due to numerous side effects, but they were authorized to be used in other countries. Even worse, some companies continuously produced and merchandised

foods containing unauthorized chemicals. Thus, they not only problematized the unethical attitudes of the companies but also lack of consumers' awareness of these situations.

> I found out that companies are selling illegal, unauthorized food additives. For example, there was a case when a company put prohibited coal tar food coloring in jellies and soda consumed by children and had to recall every product. Consumers suffer damage from that. From the research, I learned about unauthorized food additives that are not supposed to be used in this country. We decided to conduct our research on what kinds of problems the illegal food additives could cause to consumers.... Unauthorized food additives are officially prohibited by the country for the sake of people's health, but companies still use them. So, we got more curious about it. That's how we chose our research topic. (Interview with S3 in Group C)

Groups B and D approached the issues using scientific methods. Students in Group B noticed that manufacturing companies were using food additives for better color formation, longer preservation, and enhancing the flavor even though food additives could cause serious problems in human bodies. They also found that some companies were fighting strongly against organizations objecting to the consumption of sodium nitrite. Thus, they decided to examine the health risks of sodium nitrite contained in ham, sausage, and smoked meat by doing literature reviews and to conduct an experiment to detect sodium nitrite in foods. From a brief survey of people around them, they realized that not many people checked whether the ham they wanted to buy contained sodium nitrite nor did they cook the ham in a way that could reduce its consumption. Thus, they wanted to inform people with evidence from science experiments. They purchased processed meats from the market, and then carried out experiments controlling for variables such as water temperature of boiling ham, size of ham, and duration of boiling time.

> A lethal dose of sodium nitrite is 4–6 g. If you consume more than this, the hemoglobin in your blood starts an oxidation reaction, losing its ability to carry oxygen and leading to death. There was a research result showing that eating half a serving of hot dog every day is dangerous. Of course, sodium nitrite suppresses botulinum in ham, sausage, and smoked meat. It also makes the color formation in processed meat better. However, most people have no idea how much sodium nitrite is in their foods. (From Group B presentation)

Group D also designed a scientific experiment. From their internet search, they found that food additives are not only in fruits but also in fishcakes, cheese, bread, and cookies, and, moreover, they can be extremely harmful to human body. They thought that preservatives could be even more detrimental to children because related regulations were likely to be set for adults. Thus, they tried to find ways to replace chemicals and found that some natural extracts could replace them. They chose grapefruit extract as a natural preservative and investigated its function as a preservative.

> Preservatives are the most commonly used product among food additives: We can say they are used in almost every food product. For example, even in fruits, while no other food additives are used, preservatives are certainly used. Well, we import mangoes or frozen blueberries from foreign countries such as Chile, and they all use preservatives. So, they decided to find alternative, natural preservatives. Experiment plans began with selecting different types of preservatives, then we tried various natural preservatives. We then selected the top three most effective ones to try them on food in order to find out which one would preserve the food best. (Interview with S3 in Group D)

They placed rice with grapefruit seed extract and processed rice with artificial preservative in the same environment and observed mold growth, and confirmed the effects of grapefruit extract.

4.3   *Willingness to Act*

Most of the students expressed a feeling of accomplishment from their own research experience. Their experience of planning and executing research on their own increased their confidence and motivation that they could do something to solve the issues of food additives. In addition, through research, they discovered new aspects of the issue that they had not recognized before – sometimes unreasonable and unjust aspects – which led them to feel responsibility to share their findings with others. The following excerpts show this.

> We were doing various activities related to the topic. It was great to learn the new things by actually doing it, not just than simply listening to the lecture. There was a joy of learning the new things, sharing what we discovered with other classmates, and helping others with difficult problems. (From the journal of S2 in Group D)

As much as the students were passionate about their research, they wanted to share the results with others and do something that could help others. They

tried to find ways to enact their willingness. Some students wrote letters to city mayors, and some created informative posters for consumers. For example, Group C planned campaigns and videos to inform people about potential health risks that unauthorized chemicals caused. Group A wanted to raise their voices to uncover unethical attitudes of fast-food companies only pursuing profits.

> I would like to lead people to change their understanding of food so that they would pursue a healthy diet rather than only taste. What can I do? I can participate in campaigns to pressure the government to make more regulations about food additives…. I will create videos emphasizing the dangers of unauthorized food additives and share them with other people. (From the journal of S1 in Group C)

> I thought it would be great to have a chance to meet people in fast-food companies such as McDonald's and Burger King. I want to ask them if they know about the negative effects of the hamburgers that they make. I wonder how they would react when I tell them things like "Products your company manufactures are destroying the environment and damaging our health." Of course, it is unlikely that those companies would let me carry out an interview with them, but if possible, I would like to. (From the journal of S1 in Group A)

> Actually, companies are huge. It was somewhat overwhelming for a small group of four people like us to dig into such an enormous issue related to a mega-size company…. If we could do it, I am willing to do it, though. (Interview with S1 in Group E).

Some students anticipated some obstacles they might face when raising their voices against the unjust behaviors and attitudes of companies. As S1 in Group E mentioned above, some students knew that they could rarely affect companies or directly resolve the problems against "mega-size companies." Some might feel helpless or overwhelmed about the issues. However, it was noticeable that they attempted to find some things that they could do in their current positions based on their research experience and findings. The following excerpt shows another example.

> We detected sodium nitrite even in the ham that said, "does not contain sodium nitrite." I wanted to be more accurate and precisely measure the amount of sodium nitrite using more various detection methods. If it were true that this ham contained sodium nitrite, does that mean

this company has been deceiving us? If so, I feel inclined to publicly announce this lie via media. I consider this a fraud against the public. Since food additives such as sodium nitrite are extremely harmful to the human body, I think such truths should be announced to all. (From a journal of S_3 in Group B)

When doing the experiment in the program, students in Group C were upset when they observed that ham that claimed not to contain any sodium nitrite turned out to contain it. At first, they checked the procedure of their experiment and partly admitted its limitations, but they also began to doubt whether the nutrient information on the ham was accurate. They wanted to disclose the falsity of the information but felt the need of further investigate for more accurate data. Using the research findings, they at least shared tips for healthy eating of processed meats with others (e.g., after you boil ham in water for a short amount of time, it decreases the consumption of sodium nitrite).

5   Discussion and Implications

Socioscientific issues, including the issues of artificial food additives, can be introduced using various instructional approaches. In this study, we provided students an opportunity to conduct their own research on the issues and guided them to successfully complete the research. As the results indicated, we found some strengths of the research-based approach for SSIs in widening students' understanding of the issues and willingness to take action.

First, the students very clearly appeared to widen their understanding of the issues as they conducted their research. In particular, drawing SSI maps helped them see diverse stakeholders and intricately intertwined relationships among them. They intuitively understood that science and technology, including artificial food additives, could be regarded as a complex network where various stakeholders were entangled, and that this inevitably caused ethical and social problems such as inequality, social injustice, or abuse of power relationships among the stakeholders. This result is consistent with the findings of the STEPWISE program (Bencze, 2017). Examining diverse stakeholders and being open to diverse perspectives are critical elements in SSI learning (Kahn & Zeidler, 2016; Sadler, Barab, & Scott, 2007). Beyond this, in this study, students' direct recognition of the problematic nature of science and technology led them to identify research topics to explore and to find ways to solve them. This was "somewhat surprising" to them when they realized this in the beginning

and at the same time could build personal rationales for why they should pay attention to the issues as citizens and what they figured out through research. As the self-determination theory explains (Deci & Ryan, 2000), the students developed their own motivation for the research.

Second, the students in this study expressed amazement at the fact that the food additives that had been used to enhance the taste of food and increase shelf life were associated with many stakeholders. Some students felt uncomfortable seeing the social injustice and unethical elements from the maps and wanted to resolve them. As Bencze and Krstovic (2017) mentioned, awakening to such aspects became a driving force for them to shape their research topics and to start critical exploration. As they undertook their research, they became more aware of the severity of problems. Most insisted that they should inform others about the potential dangers of food additives and struggled to find more practical and concrete solutions to resolve the serious issues on the basis of their research findings. Some students also showed a passion for the further research in this line. As previous studies (e.g., Herman, 2015; Lee et al., 2012, 2013) have mentioned, students' perceptions about the nature of the issues significantly influenced their willingness to engage in certain action.

Third, students' understanding of the issues was deepened through research experience. They conducted scientific experiments or surveys to construct reasonable responses to the research questions with clear evidence. Regardless of whether they conducted scientific research or social science research, they brought up many questions to clarify their understanding and to explore further. Skepticism and on-going critical inquiry are very important clues to show to what extent people are engaged in reasoning about socioscientific issues (Sadler, Barab, & Scott, 2007; Romine, Sadler, & Kinslow, 2017). Such clues were often found in their discourses, and they themselves admitted that they were able to obtain a deeper and broader understanding of the issue.

In sum, we would like to suggest practical implications for teaching SSIs. In SSI teaching, it is essential that teachers provide students opportunities to see the complexity of SSIs. SSI maps can be a good instructional tools because they visualize the nature of SSIs in a complex network among various stakeholders. Student-led research experience can also promote more holistic engagement of students in SSIs (Birmingham & Calabrese Barton, 2014; Kim & Lee, 2019). Through the research, they themselves discover some issues to explore, collaboratively find ways to conduct the research, and make a commitment to share with others to make a better society. We hope that this current study will guide science teachers to take a further step when addressing SSIs.

Abbreviations

ANT	Actor-Network Theory
KSES	Korean Science Education Standards for the Next Generation
PARRISE	Promoting Attainment of Responsible Research and Innovation in Science Education
RiNA	Research-informed Negotiated Action
SSIBL	Socio-Scientific Inquiry-Based Learning
SSIS	Socioscientific Issues
STEPWISE	Science and Technology Education Promoting Wellbeing for Individuals, Societies, and Environments

Ethical Considerations

Approval to conduct this study was granted by the Ewha Womans University Institutional Review Board (IRB). The data collected from this paper has obtained the necessary clearance from the students involved in the study and their guardians. Pseudonyms are used for names of all participants.

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