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Miki Sakamoto [a], Etsuji Yamaguchi [a], Tomokazu Yamamoto [b] and Kazuya Wakabayashi[c]

[a]Graduate School of Human Development and Environment, Kobe University, Kobe, Japan; [b]Hyogo University of Teacher Education, Kato, Japan; [c]Kobe Kaisei Girl's Junior and Senior High School, Kobe, Japan

ABSTRACT

Socio-scientific decision-making necessitates reasoning from multiple perspectives and the use of trade-offs. This study examines how students decide on socio-scientific issues when they engage in an instructional intervention to enhance their socio-scientific decision-making towards consensus building that, in this study, emphasises generating solutions to resolve issues. We developed a socio-scientific issue-based unit for non-science undergraduate students focusing on an intervention that enhances their socio-scientific decision-making around issues regarding a genetically modified organism. Our intervention focused on consensus building wherein students identified multiple conflicts among various stakeholders' opinions and proposed solutions to resolve them. In particular, students considered the trade-offs of science and technology. This paper presents the results from two intervention studies in which 12 and 49 non-science undergraduate students participated. To confirm that the participants of each study achieved the goal of the curriculum unit, we analysed the solutions students collaboratively constructed at the end of the unit (Analysis 1). We then used a pre- and post-intervention approach to assess students' independent decision-making (Analysis 2). During the curriculum unit, we assigned students an essay-writing task twice and investigated the quality of their decisions. A comparison of the pre- and post-tests revealed a general shift towards higher-level responses after the intervention. Students' arguments on socio-scientific issues changed from justificatory arguments to proposals for solutions. These findings demonstrated that the instruction promoted students' socio-scientific decision-making towards consensus building. Finally, we discuss the implications for socio-scientific issue instruction and the evaluation of students' decision-making as well as provide suggestions for future work.

KEYWORDS
socio-scientific issues; decision-making; consensus building

CONTACT Miki Sakamoto msakamo@pearl.kobe-u.ac.jp Graduate School of Human Development and Environment, Kobe University, 3-11 Tsurukabuto, Kobe, Hyogo 6578501, Japan

Introduction

Socio-scientific issues (SSIs) represent complex social dilemmas related to the application of scientific principles and practices (Kolstø, 2001; Zeidler et al., 2005). In the last decade, science education researchers and practitioners have made significant advances in the use of SSIs as a context for transforming science learning (Lederman et al., 2014; Sadler, 2009; Sadler & Dawson, 2012; Zeidler, 2014). The current literature has reported on the beneficial effects of SSI interventions in terms of interest and motivation, content knowledge, nature of science, and community of practice (e.g. Sadler, 2009). Moreover, SSI approaches can be an effective means of supporting learning that is aligned with science literacy, especially the ways in which students conceptualise and use science content and practices through the exploration of complex issues (e.g. Zeidler, 2014).

Theoretical framework

Informal reasoning on socio-scientific issues

Previous studies have used an open-ended questionnaire and/or interviews to measure students' reasoning and decision-making on SSIs (e.g. Bell & Lederman, 2003; Liu et al., 2011; Sadler & Zeidler, 2005; Wu & Tsai, 2007). Many early studies of informal reasoning on SSIs were conducted qualitatively (e.g. Sadler & Zeidler, 2005). Later, some researchers in psychology also proposed quantitative measures to represent learners' informal reasoning. Wu and Tsai (2007) proposed an integrated analytical framework for learners' informal reasoning on SSIs using three indicators: decision-making modes, reasoning modes, and reasoning level or quality. Decision-making is intuitive when it is spontaneous and immediate, whereas it is evidence-based when it considers information of a factual nature. Reasoning modes are characterised by their social, ecological, economic, or scientific/technological orientations. The number of reasoning modes can also be obtained as quantitative measures. The greater the number of reasoning modes an individual learner utilises, the more he/she is oriented to reasoning from multiple perspectives. Reasoning quality describes the learner's ability to generate arguments using three components: supportive arguments, counterarguments, and rebuttals.

An SSI cannot be solved based on 'simple cause-and-effect reasoning'. Because of the multidimensionality of SSIs, socio-scientific decision-making necessitates reasoning from multiple perspectives, including scientific, environmental, and social ones (Lee & Grace, 2012). To examine students' reasoning from multiple perspectives, Lee and Grace (2012) categorised the justifications students provided in support of their decisions into six types, each representing a distinct perspective, and counted the number of perspectives invoked by each student. Some research (Liu et al., 2011; Wu & Tsai, 2007) has also generated the number of reasoning modes, an indicator equivalent to Lee and Grace's (2012) perspective.

Socio-scientific decision-making

In socio-scientific decision-making, students first need to understand and describe SSIs in terms of their complexity; second, they need to be able to generate solutions that account for multiple perspectives on the issue; and third, they must be able to critically evaluate solutions (Eggert et al., 2013; Zeidler et al., 2019). Science education research has identified the ability to use trade-offs as a crucial aspect of socio-scientific decision-making (e.g. Eggert & Bögeholz, 2010). The use of trade-offs is characterised as the ability to consider and compare the advantages and disadvantages of multiple options and is described as a compensatory decision-making strategy.

Eggert and Bögeholz (2010) administered a paper-and-pencil measurement to assess secondary students' decision-making approaches in various scenarios at different grade levels. They adopted the Rasch partial credit model to identify the progression from rather intuitive to more sophisticated decision-making. Intuitive decision-making was characterised by the use of non-compensatory decision strategies (cut-offs), that is, considering one criterion at a time. More sophisticated decision-making is described as the use of compensatory strategies (trade-offs) and being able to weight criteria and reflect on the decision-making process. Sakschewski et al. (2014) also developed a measurement instrument to assess secondary students' decision-making competencies. Papadouris and Constantinou (2010) investigated sixth-grade students' approaches to comparing rival solutions in several socio-scientific decision-making contexts and demonstrated that students could not select an effective decision-making approach for different socio-scientific tasks in a consistent manner.

SSI-based instruction

A number of instructional frameworks for teaching SSIs exist in the literature (Ratcliffe & Grace, 2003; Sadler et al., 2017). For example, Friedrichsen et al. (2016) presented a model for SSI instruction that highlights (a) a focal issue, (b) the interaction between science ideas and practices, (c) social connections, (d) the use of information and communications technologies (ICT), and (e) a culminating experience that encourages students to synthesise their ideas. In Friedrichsen's instructional model (Friedrichsen et al., 2016), SSI-based instruction should start with the presentation of a compelling issue. This model posits three interacting elements as the primary substance of students' learning experiences: social connections, science ideas and practices, and ICT. Students should substantively apply science ideas and practices as they negotiate the focal issue. They should also have opportunities to consider the focal issue's social complexities, which often interact with the ways in which the underlying science is interpreted or applied. As they make sense of the focal issue, students should interact with ICT to access and analyse new ideas as well as share their ideas with classmates or broader audiences. The culminating experience is designed as an activity for students to synthesise their experiences with the focal issue and apply their learning throughout the unit. In a culminating experience, students return to the focal issue and apply their scientific understanding to grapple with the social aspects of that issue.

Instructional interventions for socio-scientific decision-making

Since students tend not to be equipped with socio-scientific decision-making abilities, several studies have developed various instructional interventions to improve students' socio-scientific decision-making performance. Evagorou et al. (2012) adopted an online argument construction tool (argue-WISE) to support students' data collection when deciding on an environmental issue. Grooms et al. (2014) also used scientific argumentation around SSIs in their interventions. Some research has analysed students' group discussions in detail (e.g. Grace, 2009; Jiménez-Aleixandre, 2002).

Fang et al. (2019) proposed a theoretical framework to characterise three phases of socio-scientific decision-making: formulating the decision-making space, positing a suitable decision-making strategy to make a decision, and reflecting on the decision-making process. Some intervention studies have provided a decision-making framework, decision-making strategy training, or prompts to reflect on the choice of the decision-making strategy. Ratcliffe (1997) developed a six-step structure for supporting students' decision-making as follows: options, criteria, information, survey, choice, and review. Sutter et al. (2018) added the step of 'define the problem' at the beginning. Grace (2009) adapted Ratcliffe's decision-making framework and utilised it for group discussion on the issue of biological conservation.

Various instructional interventions have been developed to support students' use of appropriate decision-making strategies, such as introducing an optimisation strategy (e.g. Böttcher & Meisert, 2013; Nicolaou et al., 2009; Papadouris, 2012) and using additional meta-cognitive approaches (Eggert et al., 2013; Gresch & Bögeholz, 2013; Gresch et al., 2013). Nicolaou et al. (2009), for example, analysed the contents of students' reports and their responses to the tests in categories representing the elements of optimisation decision-making strategies, such as the consideration of the relative weight of each criterion.

Decision-making for consensus building

These intervention studies have focused on choosing the best option or selecting among possible solutions rather than developing new alternative solutions. Although Eggert et al.'s (2013) socio-scientific decision-making questionnaire comprised items that represented the development of sustainable solutions to SSIs, they dealt with the summed score of the scale on 'developing and evaluating solutions'. Moreover, Kim et al. (2019) designed and implemented a community-based SSI programme (SSI-COMM). This programme included the phase of action-taking, wherein students look for and implement the best solutions to the issue. However, Kim et al. (2019) did not analyse students' solutions. While they examined changes in students' sense of place and character development as citizens through SSI-COMM, they did not measure each student's competency in or attitude towards looking for solutions by themselves. Could those solutions contribute to consensus building among multiple stakeholders? And could SSI-COMM improve students' competency to take action to resolve community issues, that is, the competency to look for solutions by themselves? Furthering these studies, this study therefore develops an SSI-based curriculum unit to encourage students to propose solutions to resolve the conflicts around an issue, that is, *socio-scientific decision-making towards consensus building*.

Purpose

The purpose of the present work is to examine how students make decisions on SSIs when they engage instructional intervention to enhance their socio-scientific decision-making towards consensus building. We designed an SSI-based curriculum unit for non-science undergraduate students that focused on identifying the conflicts among multiple stakeholders' opinions and proposing solutions to resolve such conflicts. The goal of the unit is that an individual student proposes solutions to resolve the multiple conflicts among various stakeholders while considering the trade-offs of science and technology (development of functional rice created by genetic modification). The research reported here was conducted in two studies. The first was a pilot study. In the second study, we conducted a full-scale verification. To confirm that the participants of each study achieved the goal of the curriculum unit, we analysed the compensatory solutions the participants constructed in small groups at the end of that unit. This research used a pre- and post-intervention approach to assess students' spontaneous and independent decision-making. During the curriculum unit, we assigned students an essay-writing task twice and investigated the quality of students' decisions. We hypothesise that after students experience decision-making towards consensus building in collaborative environments, they spontaneously propose solutions to resolve the conflicts among various stakeholders the next time they make a decision on their own.

The present research focuses on decision-making in which participants develop alternative solutions to an issue to build a consensus among stakeholders instead of choosing the best option among existing solutions. Previous studies, however, have not provided an intervention framework for this kind of decision-making. This research thus contributes to the field by presenting a new SSI instructional model for decision-making towards consensus building.

Methods

Participants

The participants included 12 (7 male, 5 female) and 49 (13 male, 36 female) non-science undergraduate students for the first and second studies, respectively. All the participants were Asian and in their second or third year of studies for a four-year bachelor's degree in human development at a Japanese national university. They all enrolled in two introductory classes on science education. Before the start of the class, the students were invited to participate in this study. In the first study, all 12 students signed a consent form and completed the essay-writing task. In the second study, which was implemented with different students, 49 of the 65 students enrolled in the class, signed a consent form, and completed the essay-writing task. The participants were majoring in education or psychology and had no previous experience of formal SSI learning. All the students participated in this study as volunteers, without compensation.

Curriculum unit

The goal of the curriculum unit was to provide university students with experience of decision-making towards consensus building regarding SSIs and enable them to make better decisions spontaneously. The K-12 national curriculum in Japan provides only minimal coverage of the content of SSIs, and few opportunities to study SSIs are provided in university curricula. Therefore, most university students in Japan have never studied

SSIs. Hence, this study is considered to have important implications for science education for undergraduate students in Japan.

The curriculum unit was developed by three university researchers and a graduate student specialising in SSIs in science education (the four authors of this paper). The development members met regularly for about four hours every two weeks for three months to carry out the actual development work. This included the selection of SSI topics and design of the instructional plan, learning activities, learning materials, and assessment tests.

A university researcher, one of the development members, taught the curriculum unit. This researcher had over 20 years of teaching experience at the university level and previous experience of teaching other SSI-based instruction units in a science education course at his university.

The development of a genetically modified organism—Japanese cedar pollinosis-alleviating rice—was selected as the focal issue in our curriculum unit. Cedar pollinosis-alleviating rice is functional rice created by genetic modification to alleviate cedar pollinosis allergy and is made by introducing a protein similar to the one that causes cedar pollen allergy into the rice (Takano, 2016). Since this rice has proteins similar to those that cause cedar pollen allergy, the oral intake of this rice can lead to immune tolerance and thus be used to treat cedar pollen allergy. Furthermore, it is assumed that no side effects are caused by eating this rice because the protein introduced is different from the protein that causes cedar pollen allergy (Takano, 2016). We considered the development of cedar pollinosis-alleviating rice as an SSI for several reasons. First, the development of this transgenic rice has been controversial among stakeholder groups. While the developers have claimed the benefits as a treatment, farmers, consumers, researchers, and others have expressed their concerns. Additionally, the cultivation of this rice in isolation plots was previously stopped because around 70,000 signatures were collected calling for the cessation of its cultivation (Hori, 2004). Therefore, it was concluded that the issue has both a scientific aspect, such as genetic modification technology and suppression of allergic reactions, and a social aspect, such as conflicts among people of various social positions, and thus meets the definition of an SSI.

The curriculum unit consisted of six sessions (each 90 minutes) and included two phases. Phase 1 (sessions 1–4) included the information search for science ideas surrounding the issue and arguments for both sides. Phase 2 (sessions 5 and 6) required decision-making towards consensus building, that is, the generation of two-sided arguments containing some solutions to resolve multiple conflicts. The theoretical framework of the unit's design was the SSI instruction model presented by Friedrichsen et al. (2016)—a focal issue, the interaction between science ideas and practices, social connections, the use of ICT, and a culminating experience—as well as instructional interventions for socio-scientific decision-making. Previous intervention studies have provided decision-making strategy training (e.g. Papadouris, 2012). Our strategy training provided in phase 2 focused on decision-making towards consensus building, wherein students look for solutions to the issue (Kim et al., 2019).

The curriculum units in study 1 and study 2 have the same structure. Based on the findings from implementing the lessons in study 1 as a pilot study, the details of the learning activities were modified and then the modified versions were implemented in study

2. The content of the instructional sequence and corresponding elements of the instructional model are explained in Table 1.

In phase 1, the students learnt about the scientific background of the process and treatments of allergies and the genetically modified organism (scientific ideas). In collaborative sessions, the students then explored opinions favouring or opposing the focal issue, thus examining the benefits and drawbacks of the genetic modification technology (social connections). The favouring or opposing opinions were taken from a doctor, patient, scientist, farmer, and so on. To explore the opinions, the students utilised study materials including findings from academic papers on SSIs and information in the real world, such as open-source data cited from websites, to elicit evidence-based decision-making (ICT). The students then completed the first essay task (pre-test). Each student wrote down arguments referring to the materials as if they were making a public decision on the development of cedar pollinosis-alleviating rice.

The focus of our study is on the second phase of this intervention. In phase 2, the students were provided with a decision-making strategy for consensus building and had to apply it correctly in cooperative learning settings. They clarified the complex relationships among the views and identified the conflicts (scientific practice). In the pilot study, the students identified 15 conflicts, and the teacher selected seven fundamental ones. In the second study, we tried to optimise this redundant and time-consuming learning activity. In the curriculum unit of the second study, the teacher demonstrated a model of how to identify conflicts and the students were guided to identify six such conflicts: financial gain, medical expenses, treatment, side effects, development of genetic modification technology, and environmental impact. Finally, the students were engaged in group activities for consensus building. They were provided with worksheets with scaffolding to construct solutions to resolve the conflicts and revised these solutions through peer critique. They tried to elaborate on the solutions that could convince multiple stakeholders and reach a consensus (culminating experience). After the final session, the students completed the second essay task (post-test). This task was identical to the first one and was implemented with the whole class in the first study and as individual homework after the unit in the second study. There was no time limit for the students

Table 1. The content of the instructional sequence and corresponding elements of the instructional model

Phase	Contents and learning activities in this programme	Elements in Friedrichsen's instructional model
Information search	Japanese cedar-pollinosis-alleviating rice (i.e. a functional rice developed through genetic modification to alleviate cedar pollinosis allergy.)	Focal issue
	• Learn about the scientific process and treatments of allergies, and the genetically modified organism. • Clarify the complex relationships among views and identify the conflicts.	Science ideas and practices
	Learn using the video materials on YouTube and the sources listed in various materials.	ICT
Decision-making for consensus building	Explore opinions favouring or opposing the focal issue and examine the benefits and disadvantages of genetic modification technology.	Social connections
	Construct solutions to resolve conflicts and revise these solutions through peer critique.	Culminating experience

to accomplish each essay task, and the time used by the students was approximately 40 minutes.

Data source

This study draws on two types of data. The first data source (i.e. the compensatory solutions the participants constructed during the learning activity of the culminating experience at the end of the unit) was analysed to verify the achievement of the unit's goal. The second source (pre- and post-tests) were used to explore the improvement in the quality of students' decision-making on the focal issue in the curriculum unit.

Analysis

To confirm that the participants of each class achieved the goal of the curriculum unit, we analysed the compensatory solutions the participants constructed during the learning activity of the culminating experience at the end of the unit (Analysis 1). Examples of the solutions from this survey are presented in Appendix A. The unit of analysis was the number of solutions the participants constructed and types of conflicts they tried to resolve.

Analysis 2 dealt with the quality of students' decision-making. For the first research question, we analysed students' justifications in supportive arguments or counterarguments in terms of the conflicts they tried to solve, following the methods of Lee and Grace (2012). In the first study, seven categories were defined to classify conflicts, which were identified during instruction. Six categories were defined during the instruction for the second study.

This study explored students' decision-making mainly in terms of the level or quality of the decision, focusing on dealing with trade-offs (for the second research question). The quality of students' decisions was analysed utilising three components: supportive arguments, counterarguments, and proposals for solutions. The assessment criteria were two-sided arguments and arguments containing some solutions to resolve one or more conflicts. The evaluative rubric and examples from this survey are presented in Table 2. More examples are shown in Appendix B. The rubric comprises six levels, the lowest of which includes only an unsubstantiated claim. Successive levels progress to include justifications, counterarguments, and proposals. Following the rubric of Eggert et al. (2013), students' solution proposals were categorised as being at a 'higher level' if they were detailed and intended to resolve multiple conflicts. We regarded such proposals as the result of reasoning from multiple perspectives. We also classified the types of conflicts treated in decision-making as a supplementary analysis.

These indicators were established based on our theoretical framework as well as the results of the pilot study. The development of the rubric was an iterative process driven by both theory and data. A preliminary rubric was refined interactively until a set of empirically derived levels was identified. The data analysis was iterative: the raters moved back and forth between the rubric and data until saturation was achieved (Denzin & Lincoln, 2018).

Table 2. Rubric for assessing the quality of the students' decisions and examples from this survey

Level	Description	Examples
0	Made only simple claims, without justification.	I agree.
1	Made claims justified by supportive arguments, but there were no counterarguments (justificatory arguments: one-sided).	I would like to argue from the position of opposing the development of cedar-pollinosis-alleviating rice. I do so because according to the opinion of an opposing doctor, drugs currently in use are highly effective and their side effects are known [*supportive argument*s].
2	Generated supportive arguments and counterarguments (justificatory arguments: two sided).	I would like to formulate an opinion in favour of the development of cedar-pollinosis-alleviating rice. Opponents are concerned about unknown allergies and side effects that the consumption of genetically modified crops may bring [*counterarguments*], but all drugs of any sort inevitably come with side effects [*supportive argument*s].
3	Generated two-sided arguments and suggested the need for a proposal to resolve some conflicts.	I would like to formulate an opinion in favour of the development of cedar-pollinosis-alleviating rice. Certainly, some farmers are opposed to this considering the risk of the cross-contamination of ordinary rice [*counterarguments*]. Also, when it comes to the stage of actually cultivating the rice in question, it would be vital to prevent the opposing farmers' worry of rice contamination from becoming reality. It will be essential to provide farmers wishing for the development of cedar-pollinosis-alleviating rice with a thorough explanation of all that such an endeavour would entail, and to rigorously manage and cultivate the fields with cedar-pollinosis-alleviating rice [*suggest a need for solutions*].
4	Generated two-sided arguments and constructed a solution to resolve one conflict.	I would like to formulate an opinion in favour of the development of cedar-pollinosis-alleviating rice. One reason to oppose it is the dangers associated with it. Unknown side effects are one such danger. Naturally, with unknown side effects, it is not immediately clear how to deal with them, and thus the number of hospital visits may actually increase rather than decrease [*counterarguments*]. To prevent such outcomes, long-term experimentation is necessary, but the budget for such is limited. What if we invited individuals, well-informed about the dangers involved, to participate in clinical experimentation and provided them with cedar-pollinosis-alleviating rice free of charge or at low cost? [*solutions to resolve conflicts*]. This would reduce the need for developers to spend large amounts of money on long-term experimentation, as well as provide those agreeing to clinical testing of cedar-pollinosis-alleviating rice with extremely low-cost treatment. After all, it is essential to prove its safety in order for it to be fully accepted by society [*conflicts of side effect*s].
5	Generated two-sided arguments and constructed a solution to resolve multiple conflicts.	I would like to formulate an opinion from the standpoint of opposing the development of cedar-pollinosis-alleviating rice. Advances in genetic modification technology will contribute to the future development of various other types of functional rice and will also benefit developing countries and rural areas [*counterarguments*]. If we could just reliably eliminate side effects and other risks to health as well as the environmental destruction caused by the spread of modified genes, the value this advancement could provide seems very much worthy. For example, what if at first only a small number of farms were to cooperate with development companies in genetic

(*Continued*)

Table 2. Continued.

Level	Description	Examples
		modifications, in a limited area, isolated from other farms, with rice grown only indoors and distribution limited to take place directly between development companies and farms? [*the first solution to resolve conflicts: Environment*]. This would prevent contact with other plants and contamination of conventional rice, and thus prevent spread. Furthermore, by delaying practical use of cedar-pollinosis-alleviating rice until its safety has been confirmed by repeated clinical experiments, and allowing it only in cases wherein conventional treatments have failed and the person in question applies for and consents to its use, I believe a minimum level of safety can be guaranteed. [*the second solution to resolve conflicts: Side effects*]

Results

Analysis 1: Solutions students constructed

First, to verify the achievement of the unit's goal, that is, to apply a decision-making strategy for consensus building, we analysed the learning activities of the culminating experience. Students constructed solutions to resolve some of the conflicts and filled out the worksheet. Examples of the solutions proposed by the students include the following:

> It seems to me that it is too risky to grow in the paddy fields of Japan. Therefore, I would suggest that it is better to grow them only in factories and laboratories. *(#F1, a solution to resolve the conflict of environment)*

> The government could impose a tax on cedar pollinosis-alleviating rice and give the tax revenue as a subsidy to ordinary farmers who are suffering from the decline in sales of traditional rice. *(#M1, a solution to resolve the conflict of financial gains)*

We classified the students' solutions according to the types of conflicts they tried to solve. Table 3 shows the results. Several solutions were proposed for the conflicts regarding the treatment and side effects in both the first and the second studies. In the second study, a certain number of solutions were also created for conflicts not addressed in the first study, such as financial gains and medical expenses. Averages of 3.4 (SD=.77) and 2.5 (SD=.82) solutions per person were proposed for the first and second studies, respectively. These results indicate that the goal of the curriculum unit was achieved in both classes.

Table 3. Number of solutions participants constructed for each conflict during the learning activities of consensus building.

	Conflicts						
	Treatments	Side effects	GM technology	Financial gains	Medical expenses	Environmental impacts	Others
First study							
Number of solutions	10	7	6	3	3	5	7
Second study							
Number of solutions	31	19	16	21	19	21	-

Note: GM = genetically modified.

Analysis 2: Quality of students' decision-making

The preliminary data analysis in the first study demonstrated that the number of conflicts mentioned in the students' justifications increased significantly after the intervention (average 3.9 (SD=1.08) out of seven in the pre-test to 4.9 (SD=.90) in the post-test; $t(11) = 3.07$, $p<.05$). Then, the quality of the students' decisions was rated. Table 4 presents the distributions of these levels in the pre- and post-tests. A comparison of the pre- and post-tests revealed a general shift to higher-level responses after the intervention ($T=78.00$, $p<.01$). Eleven out of the 12 students were able to propose some solutions in the post-test, while no solution was constructed in the pre-test.

The data obtained from the second study were analysed in detail. First, the students' justifications in supportive arguments or counterarguments were analysed in terms of the conflicts used. Figure 1 displays the frequency data of each conflict used in the pre- and post-tests. The conflict of treatment was used the most; 80% or more of the participants used this aspect of information or evidence to make their arguments. Figure 2 illustrates the average number of conflicts the students used. The number of conflicts embedded in the supportive arguments remained the same, while that in the counterarguments increased significantly after the intervention ($t(48) = 1.359$, *n.s.*; $t(48) = 5.322$, $p<.001$). In the post-test, the students cited, on average, two categories of counterarguments. Therefore, they became more capable of reasoning about multiple conflicts regarding SSIs.

Next, the quality of the students' decisions was rated. To ensure the reliability of the qualitative analysis, 50% of the students' responses were randomly selected and scored by two independent raters. One of the raters was one of the authors of this paper and the other was a research assistant specialising in science education. We then calculated the interrater reliability and yielded a high value of interrater agreement ($k=.868$). All disagreements were resolved through discussion. Figure 3 presents the distributions of these levels in the pre- and post-tests. More than 80% of the arguments generated in the pre-test were justificatory without proposals to resolve the conflict and about half of the arguments were one-sided. Most of the students were able to make evidence-based decisions before the intervention, however inadequately. About 10% of the arguments were rated as level 3, as they did not provide a detailed solution themselves. In the post-test, more than half of the students were able to propose a solution for one or more conflicts. The students' decision levels increased significantly from the pre-test to the post-test ($T=841.50$, $p<.001$), with a notable increase in the number of arguments at levels 4 and 5. This means the students' arguments transformed into proposals of solutions to resolve one or more of the conflicts. Table 5 shows the utilisation rate of each conflict in the solutions students proposed in the post-test. The conflicts of financial gains, environmental impact, and side effects were treated the most in the students' solutions.

Table 4. Distribution of the quality of the students' decisions in the pre- and post-tests for the first study.

Level	1	2	3	4	5
Pre-test	4	8	0	0	0
Post-test	0	0	1	1	10

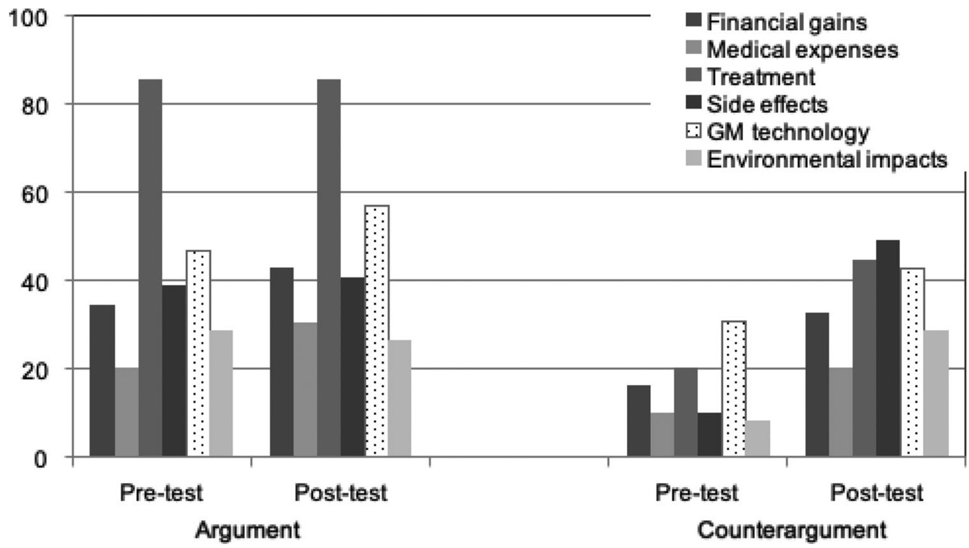

Figure 1. Utilisation rate of each conflict in students' justification in the pre- and post-tests (%). GM = genetically modified.

Discussion

This study examined how students made decisions on SSIs when they engaged in a cooperative instructional intervention to enhance their socio-scientific decision-making towards consensus building. The analyses were twofold. The first dealt with the solutions students collaboratively constructed at the end of the unit. The second dealt with students' spontaneous and independent decision-making in the essay-writing tasks. The findings of Analysis 1 showed that our decision-making intervention in structured cooperative learning settings enabled students to identify the conflicts around the issue and propose solutions to resolve those conflicts. The findings of Analysis 2 showed that students' arguments of socio-scientific decision-making changed from justificatory arguments to proposals for solutions after the intervention. The detailed analysis of the data from the second study revealed that one-sided arguments diminished and that the number of conflicts embedded in counterarguments increased in the post-test. Wu and Tsai (2007) showed that it is relatively difficult for participants to generate counterarguments and that students' construction of supportive arguments does not significantly

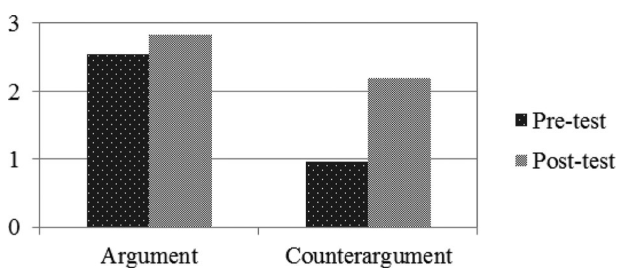

Figure 2. Average number of conflicts invoked among students' justification in the pre- and post-tests.

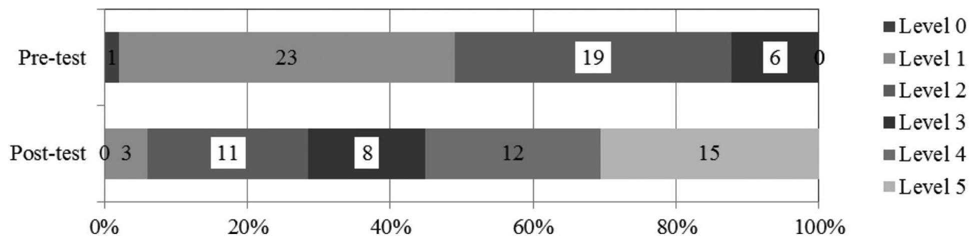

Figure 3. Distribution of the quality of the students' decisions in the pre- and post-tests for the second study.

Table 5. Utilisation rate of each conflict in students' solutions

Conflict	Financial gains	Environmental impacts	Side effects	GM technology	Treatments	Medical expenses
(%)	51.85	51.85	44.44	22.22	14.81	7.41

Note: GM = genetically modified.

correlate with their construction of counterarguments. The significant increase in the conflicts embedded in students' counterarguments in our study demonstrated that students became more capable of reasoning from multiple perspectives regarding SSIs (Lee & Grace, 2012). Moreover, solutions for multiple conflicts related to the issue as well as those for only one conflict were developed. These results demonstrated that the intervention in the cooperative training setting promoted students' socio-scientific decision-making towards consensus building.

Implications

This research has implications for both SSI instruction and the evaluation of students' decision-making. First, few intervention studies have focused on developing alternative solutions that contribute to consensus building among multiple stakeholders. The theoretical framework of the unit's design was the model of SSI instruction presented by Friedrichsen et al. (2016) and intervention studies that provided decision-making strategy training in cooperative learning settings (Böttcher & Meisert, 2013; Nicolaou et al., 2009; Papadouris, 2012). Eggert et al. (2013) demonstrated the effects of cooperative training strategies on students' socio-scientific decision-making, including the measurement of 'developing and evaluating solutions'. Our findings are in line with a large body of research that has identified the beneficial effects of structured cooperative learning settings on students' learning outcomes if task complexity is high. The analysis of the final learning activities and post-test showed that the combination of this SSI instruction model and decision-making strategy training was also effective for the curriculum unit to enhance socio-scientific decision-making, particularly in generating solutions towards consensus building.

The current study sheds light on ways to support students in considering perspectives that vary from their own and resolving complex and ill-structured issues. In the later phase of the curriculum unit, students were trained to identify the conflicts among multiple stakeholders' opinions and construct solutions to resolve each conflict. Then, they were guided to review their solutions to assess whether such solutions would convince the stakeholders involved. The learning activities and scaffolding embedded in the curriculum units developed in this research could be a new component to facilitate students' decision-making behaviours, especially the formulation of the decision-making space and reflection of decision-making (Fang et al., 2019). These could be integrated into instructional interventions that use scientific argumentation or group discussions around SSIs (Grooms et al., 2014; Grace, 2009; Jiménez-Aleixandre, 2002) as well as those focusing on students' meta-cognition in socio-scientific decision-making (e.g. Gresch & Bögeholz, 2013).

Second, implications for how to evaluate socio-scientific decision-making can be drawn from our results. Wu and Tsai's (2007, 2012) analytical framework adapts rebuttal as a component of reasoning quality. Although Kim et al. (2019) implemented an SSI programme that included the phase of action-taking, they did not analyse students' solutions. Hence, no analytical framework exists for students' socio-scientific decision-making towards consensus building. This research developed a rubric and evaluated students' evidence-based decision-making as well as decision-making towards consensus building. As discussed in the Introduction, current research on SSI decision-making includes many studies that ask students to choose one option from multiple options (e.g. Sutter et al., 2018; Papadouris, 2012). In the future, when research that requires each student to create a solution, as in this study, is initiated, the evaluative rubric presented herein could be used.

Limitations and future research

This study's findings demonstrated that our instruction promoted students' socio-scientific decision-making, both in their reasoning from multiple perspectives and in their decision-making towards consensus building. However, some conflicts were utilised less to propose solutions. Providing the framework for students to analyse and develop solutions for such conflicts may bring about more proposals to resolve multiple conflicts, that is, level-5 decisions. Based on these results, we could improve our instructions to enhance students' decision-making further.

The assessment in this study focused on generating two-sided arguments that contained solutions to resolve multiple conflicts. The next step towards consensus building is to negotiate with stakeholders based on the proposal and reach a consensus. In our strategy training provided in phase 2, students collaboratively constructed solutions and revised them considering the favouring or opposing opinions from stakeholders. Students struggled to convince multiple stakeholders and reach a consensus during this learning activity. If we had recorded and analysed the group interactions in this activity, we would have obtained suggestions for another phase of actual consensus building. Future studies could thus explore the whole process of scientific decision-making towards consensus building.

Notes on contributors

Miki Sakamoto is a Professor at the Graduate School of Human Development and Environment, Kobe University in Japan. Her research focuses on how students learn about science and technology in modern society and how teachers support students' learning.

Etsuji Yamaguchi is an Associate Professor at the Graduate School of Human Development and Environment, Kobe University. His research interests involve student learning in socio-scientific issues and science teacher education.

Tomokazu Yamamoto is a Professor at the Hyogo University of Teacher Education in Japan. He is interested in how to support students learn about scientific argumentation.

Kazuya Wakabayashi is a teacher at the Kobe Kaisei Girl's Junior and Senior High School in Japan. He was a graduate student at the Graduate School of Human Development and Environment, Kobe University.

ORCID

Miki Sakamoto http://orcid.org/0000-0002-3111-3214
Etsuji Yamaguchi http://orcid.org/0000-0001-5140-1136
Tomokazu Yamamoto http://orcid.org/0000-0002-2300-3736

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Appendices

Appendix A. Examples of students' solutions to the issues presented in this survey

A.#Conflicts of Environmental Impacts

- How about if they make a plastic greenhouse to prevent pollen from spreading to the outside?
- How about if a whole village try to grow only cedar-pollinosis-alleviating rice?

B.#Conflicts of Treatments

- Since radical therapy using artificial proteins is not yet in the research stage and has not yet been put to practical use, we should focus on experiments now and hope to be able to develop such therapy sooner or later instead of proceeding with it immediately.
- Starting with cedar-pollinosis-alleviating rice, we aim to create blends of multiple functional rice for other causes of hay fever, such as cypress, and to prescribe blended rice for different types of people.

C.#Conflicts of Side Effects

- Put a warning on the package and leave it to the buyer to decide for himself [sic].
- To develop a treatment for hay fever without any side effects [sic].
- Because the side effects of cedar-pollinosis-alleviating rice may be unknown, it should be put to practical use only after a long-term toxicity study.

D.#Conflicts of Genetically Modified Technology

- Since there may be unforeseen health hazards, we will examine whether it is safe for humans to take this drug by repeated experiments and observations. In the meantime, no use shall be permitted.

- Research on the technology of genetic modification may be carried out, but will not be released until the safety of the product is recognised by experts and others.

E.#Conflicts of Financial Gains

- The government should provide subsidies to rice farmers who have been growing traditional rice if development is to proceed.

F.#Conflicts of Medical Expenses

- To develop another functional type of rice for allergens other than cedar [sic].
- We will not bring it to the market until we can develop it at low cost.
- Aiming to reduce healthcare costs for another disease [sic].

Notes: Cedar-pollinosis-alleviating rice refers to functional rice created by genetic modification to alleviate cedar pollinosis allergy.

Appendix B. Examples of students' decisions from this survey

- Level 1

I would like to argue from the position of opposing the development of cedar-pollinosis-alleviating rice. There are three reasons for this. First, growing genetically modified crops encourages the spread of such crops by crossing with conventional varieties. Second, eating cedar-pollinosis-alleviating rice is useless for sufferers of pollen allergies caused by other allergens. Eating different types of rice for different types of allergens is very expensive and time consuming. Third, it is unlikely to be more effective than currently used medicines for radical therapy, and cedar-pollinosis-alleviating rice is not effective for patients who do not respond to existing medicines. I believe that if the mechanism of healing is the same, existing medical products are safer. I believe that existing medical products are safer if the mechanism of healing is the same [*supportive arguments*]. For these three reasons, I am opposed to the development of cedar-pollinosis-alleviating rice.

- Level 2

I would like to formulate an opinion in favour of the development of cedar-pollinosis-alleviating rice. A major reason for this is the possibility of reducing healthcare costs [*supportive arguments*]. If the alleviating rice can lower the overall healthcare costs, it will benefit not only the patient but everyone. However, I think the contrary view should be taken seriously. Because the side effects are still unknown [*counterarguments*], it is necessary to try to consume only a small amount. It is also necessary to establish a system by which whether or not to take the drug is determined based on the advice of a doctor.

- Level 3

I am not opposed to the development of cedar-pollinosis-alleviating rice, but I do not think it should be commercialised right now. Cedar-pollinosis-alleviating rice is a new treatment for cedar pollen allergy that lacks the disadvantages of conventional medicines and treatments for cedar pollen allergy. Its development and practical application could create agricultural employment as well. It is certain that cedar-pollinosis-alleviating rice will bring a lot of hope [*supportive arguments*]. However, I do not think we should move forward with practical applications too quickly.

There are two reasons for this. First, the side effects of cedar-pollinosis-alleviating rice are not yet known. Cedar-pollinosis-alleviating rice is still in the development stage, and its effectiveness and side effects have not been clarified. Second, there is a risk of cross-pollination and contamination. Cedar-pollinosis-alleviating rice is a genetically modified crop that has never existed in the ecosystem. However, it is very difficult to eliminate the possibility of cross-pollination and contamination, even if the rice is grown separately from conventional rice. In fact, cases of cross-pollination and contamination have occurred in the United States and Mexico in the past, and we cannot guarantee the ecosystems or the 'safety and security' of the crops [*counterarguments*].

For these two reasons, I think that we should develop cedar-pollinosis-alleviating rice, but we should examine various possibilities and risks before proceeding with its practical application [*suggest a need for solutions*].

- Level 4

I am in favour of the development of cedar-pollinosis-alleviating rice. The reason for this is that we feel it can create many advantages. Its first merit is that the treatment is simply eating the rice every day, which does not have the side effects that symptomatic treatments have and does not require as much effort or burden as existing treatments [*supportive arguments*]. An opposing view is that cedar-pollinosis-alleviating rice may have unknown side effects. Although it is said to be safe, other side effects may be unearthed in the future [*counterarguments*]. However, I think it is a matter for the seller to explain at the time of sale and for the buyer to decide what to do, and there is no need to stop developing it. Another merit is that if we succeed in developing cedar-pollinosis-alleviating rice, we can apply the technology to develop other pollen allergy mitigation rice [*supportive arguments*]. Therefore, I am in favour of development because there are more advantages.

However, although I agree with developing this treatment, we need to be very careful about the method and its practical application. For example, in order to prevent the spread of recombinant genes by cross-pollination and to avoid revenue loss for farmers, it is necessary to restrict growth of this rice to indoor cultivation only [*solutions to resolve conflicts*].

- Level 5

I am in favour of the development of cedar-pollinosis-alleviating rice. The development of this rice will increase the number of treatment options. This allows for the choice of a method that is appropriate for each patient. If patients who have been hesitant to try radical treatment because of the frequency of hospital visits utilise this option, national health care costs will be reduced in the long run. This could help reduce the cost of insurance premiums [*supportive arguments*].

Certainly, given the effectiveness of current medications, it may be better for physicians to use only those existing medications [*counterarguments*]. However, it would be nice if we could develop functional rice to alleviate cedar pollen allergies with a higher rate of efficacy, and it might give rise to technologies that could improve the efficacy of current medicines.

I think, though, that we should be cautious about practical applications. We should conduct experiments to determine the efficacy and side effects of the rice and wait for reliable experimental data before we put it to practical use [*the first solution to resolve conflicts: Side effects*]. In addition, distribution channels should be limited, and production should be carried out indoors [*the second solution to resolve conflicts: Environment*]. This is to prevent cross-breeding with other breeds and its impact on the environment. Before growing cedar-pollinosis-alleviating rice, farmers should be obligated to take measures to prevent the spread of pollen, and they should only grow it with permission [*the third solution to resolve conflicts: Financial gains*]. Thus, even if the profit is high, the net profit will be low because of the cost of the preparation. This will reduce the disadvantages for farmers who grow traditional rice.

Notes: Cedar-pollinosis-alleviating rice refers to functional rice created by genetic modification to alleviate pollinosis allergy. Redundant statements were omitted.