Development of a Climate Change SSIBL-STEAM Program Aligned to the National Curriculum for SSI Elementary School in Korea

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Received: 28 February 2022 | Revised: 24 April 2022 | Accepted: 6 May 2022

Abstract

This study describes the development of a climate change SSIBL-STEAM program that was aligned to the Grade 6 elementary school national curriculum using the ADDIE model for design. The efficacy of the climate change SSIBL-STEAM program was investigated by measuring the impact of the program on cultivating elementary students’ personalities (sociality, morality, emotion) and STEAM (Science, Technology, Engineering, Arts, Mathematics) competencies (convergence, creativity, challenge, caring). Twenty-five Grade 6 students and three public elementary school teachers participated in this study. Data were collected using two instruments designed to examine character and STEAM competencies before and after the program. Additionally, field notes and student learning outcomes were collected and qualitatively and quantitatively analyzed. The results indicated that students improved significantly in their character...
and STEAM competencies, especially morality, emotion, and convergence factors. This study was expected to be an example of the combined approach with SSIBL and STEAM.

Keywords

socioscientific issues – climate change – student character – SSIBL-STEAM – STEAM competencies

1 Introduction

Thanks to the development of science and technology, we enjoy conveniences of life that were not imagined 100 years ago, from cooling and heating systems and transportation to smartphones. At the same time, however, we are faced with unimaginable pains that were also not imagined 100 years ago, including environmental pollution, global warming, climate change, and mass destruction weapons. In the 21st century, responsible research and innovation (RRI) has emerged as a focus for researchers who advocate for increased reflection on social, economic, and ethical issues and situations caused by science and technology. RRI urges researchers to break away from the existing framework that focuses on knowledge creation and technology acquisition and instead emphasizes social responsibility in science and technology innovation. This approach emphasizes the participation of the general public, professionals, researchers, and policymakers as stakeholders in the process (Bak & Seong, 2018; Seong & Song, 2013).

In science education, socioscientific issues (SSIS) education has expanded the earlier focus of science, technology, and society education to include ethical viewpoints of science, moral and ethical reasoning of students on issues, and other aspects, such as a sense of community, character, and emotion (Zeidler et al., 2005; Zeidler & Nichols, 2009). SSIS education aims to develop a perspective that enables students to critically reflect on science and technology through understanding and resolving issues and grow into citizens with the capacity and character to respond wisely to related issues (Sadler & Zeidler, 2005; Lee et al., 2014). Accordingly, SSIS education discusses the meaning of scientific literacy, emphasizing social responsibility, practice, and participation at the level of holistic education, emphasizing the need to cultivate character and practice together (Zeidler et al., 2002; Kim, et al., 2016).
Many teachers have agreed on the necessity and effectiveness of SSI s education but feel burdened with actual classroom implementation (Witz & Lee, 2009). For example, because of the implicit belief that science classrooms should be value-neutral (Cross & Price, 1996), science teachers express the burden of dealing with political topics or addressing the moral and ethical developments of science and technology (Won et al., 2021). Science teachers have usually not considered this approach a fundamental science education responsibility (Sadler et al., 2006). In addition, there have been perceptions that teachers were afraid to introduce various aspects of the topics covered in SSI s education due to a lack of expertise and knowledge about new advances in science and technology developments (Lee & Yang, 2019; Macalalag et al., 2020).

1.1 Socioscientific Issues (SSI s) Education and Research
SSI s education has been conducted in many countries around the world through research projects such as PARRISE and IRRESISTIBLE in Europe, STEPWISE in Canada, and similar projects in Korea (Kwon & Lee, 2018; Levinson & PARRISE Consortium, 2017; Marcus, 2018). To better support teachers to be able to effectively implement SSI s in schools, this study reports on the development and implementation of an educational program in Korea that is based on the European Union’s PARRISE project. The PARRISE project was carried out for 4 years, from 2014 to 2017, centering on countries belonging to the European Union (EU). The PARRISE project integrated SSI s education, inquiry-based science education, and civics education using the concept of RRI to develop a socioscientific inquiry-based learning (SSIBL; Levinson & PARRISE Consortium, 2017). The SSIBL instructional model has students find and raise practical problems about SSI s, then collect opinions, and derive solutions through research and inquiry-based learning processes, which ideally lead to action and practice.

1.2 SSIBL Instructional Model and STEAM Education
The SSIBL model developed for this research is based on RRI’s primary goals of social satisfaction, ethical acceptance, and sustainability, and involves a three-stage educational approach based on SSI s, inquiry-based science education, and citizenship education. Recently, attempts have been made to link SSI s education with STEAM education (Choi et al., 2021; Won et al., 2021). STEAM education is an approach that converges the arts with STEM education. It is an approach that aims to provide an exciting and curious learning experience for students to explore science more actively and creatively (Connor et al., 2015). STEAM education aims to provide meaningful science experiences.
by connecting science and the natural world (Park, K.-M. et al., 2014; Mang et al., 2021). SSIs can provide excellent materials to achieve this purpose, as they can serve as a bridge between science and everyday life. Both SSIs and STEAM education have similar elements and contexts due to the interdisciplinary approach, and they pursue convergence competence (Levinson, 2018; Zeidler, 2016). By linking the two types of education, the scope of SSIs education can be expanded, and the educational goals of both STEAM and SSIs can be achieved more effectively (Mang et al., 2021). Mang et al., (2021) offer SSIs topics related to climate change education and global warming as especially fruitful curriculum topics for supporting students to address STEAM related content in the context of societal challenges presented by climate change. This is because climate change education requires an interdisciplinary and multidisciplinary approach and because natural sciences, social sciences, humanities, and engineering are directly or indirectly linked (Park et al., 2020; Yun, 2009).

1.3 Climate Change Education

Currently, climate change is one of the most urgent risks to the planet, making us reflect on the modern lifestyle that is based on fossil fuels and the negative effects of science and technology. In Korea, the topic is already quite popular as evidenced by the fact that more than a quarter of domestic SSIs programs have included the themes of environment, ecology, and energy (Park & Kim, 2018). Moreover, studies on the effectiveness of SSIs programs developed using these themes have been being actively conducted in Korea and internationally (Ko & Choe, 2013; Kim et al., 2017; Birmingham & Barton, 2013). In addition, the national curriculum has included environmental issues for about three decades in Korea. However, it has been a very small part of the curriculum, and its importance was often underestimated until 2015 when the revised national science curriculum integrated the concepts of global warming and climate change across ten curriculum subjects, including science, society, ethics, and geography (MOE, 2015). This change has resulted in many climate change education programs being conducted in various contexts, including out-of-school programs (e.g., Lee et al., 2011), creative experiential activities (e.g., Kim & Kim, 2016; Park & Kim, 2020; Kim & Kim, 2021), and as part of the Grade 7 “free” semester system in which students can engage in in-depth investigation about a topic without traditional evaluations (Kim, H. B. et al., 2015). However, programs designed for regular school classrooms have been relatively rarer than for the after-school or short-term activity context.
1.4 **Purpose of this Research**

This research seeks to fill this gap by providing a curriculum approach that is appropriate for the classroom setting. As Korea’s 2022 revised national science curriculum has mandated that ecological transformation education be included as a theme for all subjects (MOE, 2021), it will be necessary for teachers to develop more specific examples and guidelines to deal with climate change topics more broadly. We believe that the elementary level curriculum provides a particularly useful opportunity for developing cross-curricular approaches to address climate change education as one teacher generally teaches all subjects in each classroom. There have been a few examples of climate change education programs at the elementary level, including Park, S.-H. et al. (2014) who introduced a “life-changing energy climate change program” that integrated five subjects in Grade 4 and Baek and Kim (2021) who found that an action-oriented climate change program could be implemented effectively during regular school science classes in elementary schools in Korea.

This research seeks to provide clear examples of how elementary school teachers can implement climate change classes according to the revised national science curriculum by emphasizing an integrated approach to science education, including moral, character, and civic education (Lee et al., 2012). Through SSiS education, students experience various values and ethical perspectives related to the scientific issues, and it is one of the critical educational goals to cultivate personal intentions, attitudes, and values as citizens (Ko & Lee, 2017; Kim & Lee, 2017; Kim, H. J. et al., 2015; Sadler, 2009). Therefore, character can be a key indicator that can verify the impact of SSi programs (Kim et al., 2016). STEAM key competencies can be used as another program effectiveness indicator to determine the possibility of this fusion between SSi and STEAM. We expect the results of this research will help to better articulate the SSiBL-STEAM framework in further research.

2 **Research Questions**

This study aims to develop a climate change SSiBL-STEAM program through the reorganization of the Korean elementary school curriculum for Grade 6 based on the SSiBL instructional model introduced by the PARRISE project which integrated SSiS education, inquiry-based science education, and civics education using the concept of RRI to develop socioscientific inquiry-based learning. We aim to examine the impact of this program on changes in
elementary students' character and STEAM key competencies as identified by an instrument developed by Park et al. (2019) that considers creativity, communication, convergence, and care factors. The specific research questions framing this study are as follows.

1. What are the features of a climate change SSIBL-STEAM education program developed based on the Korean 2015 revised elementary science curriculum?
2. What effect does climate change SSIBL-STEAM education have on elementary school students' character and STEAM key competencies?

3 Research Procedure and Methods

3.1 Development of SSIBL-STEAM Program

In this section, we describe the development of the SSIBL-STEAM program based on a systematic instructional design method of analysis, design, development, implementation, and evaluation (ADDIE) to develop the program. The ADDIE model is an effective and sophisticated model that is rooted in the behavior-oriented learning principle and is used to develop various educational programs by efficiently connecting and improving educational goals (field requirements) and performance (Allen, 2006). In addition, because the steps are relatively straightforward and a feedback system is provided, it is convenient for developing projects to use in school settings and has been used as a universal instructional design tool (Peterson, 2003). The process for implementing the ADDIE model is shown in Figure 1.

In the Analysis stage, a literature review was conducted to understand SSIBL, SSIS education, and STEAM education. The review focused on assessing relationships between SSIBL, SSIS, and STEAM education and exploring examples of the use of these approaches for climate change education. In the Design stage, the content and achievement criteria for reorganizing the 2015 national science curriculum were searched. Prior studies were reviewed to consider what climate change educational content has previously been studied at the elementary education level. In this process, teacher researchers in this study played a critical role in identifying and re-organizing content that could be integrated across the curriculum. In the Development stage, a modified SSIBL-STEAM education model was developed using what was learned from the first two stages. Figure 2 shows the modified SSIBL model and steps.

In the first stage, Ask, scientific knowledge and various information are used to explore an SSIS and find authentic questions in real life. In the second stage, Find Out, various problem solving and exploration processes such as finding
solutions to problems in ways that include new technologies, knowledge, data collection, cooperation, experiments with others, social investigation, and discussion. In the last third stage, Act, the solution to the problem is directly implemented as an action. If a new problem arises during the practice, a solution is found and practiced again. As a result, the activities of the three stages is interconnected.

In the Development stage, three Grade 6 teachers and three researchers with environmental education expertise frequently met to discuss the SSIBL model and to develop climate change lessons using the model designed. In total, 51 lessons were developed to be used in 45-minute class periods for Grade 6. During the Implementation stage, the teacher made a class log, observed the students’ activities, evaluated students’ outcomes, and recommended changes to the
lesson designs. In the Evaluation stage, the students’ and teachers’ impressions were collected by researchers who analyzed the effects of the educational program on students’ character and key STEAM competencies. The observations and class notes of the teacher were analyzed and reflected in the evaluation results. Some suggestions for future program development were drawn based on the evaluation content.

3.2 Climate Change Content Analysis in the National Curriculum for Sixth Grade

In this section, we describe in more detail how the modified SSIBL model was applied to the 2015 national curriculum for Grade 6. Teachers and researchers worked to identify all climate change related content covered in the second semester of the Grade 6 curriculum by selecting all of the achievement standards and class activities related to climate change. Climate change and sustainable development related topics were identified in science, social studies, Korean, and ethics. For example, related content was identified throughout the curriculum, including sustainable global villages (social studies), use of electric energy (science), writing with evidence, communicating effectively, and comparing and expressing information (Korean), sustainable living, healthy eating habits (practical arts), and climate change (ethics). This content was re-organized using an action-oriented climate change education (CCE) content analysis framework (Park et al., 2020) (see Table 1) to map CCE components to the content.

| Aspects            | Areas          | Sub-areas                     | Description                                                                 |
|--------------------|----------------|--------------------------------|-----------------------------------------------------------------------------|
| Potential aspects  | Knowledge      | Scientific knowledge          | Information about climate change                                            |
|                    |                | Relational knowledge          | Knowledge of the various interactions between climate change and ecosystems |
|                    |                | Responsive knowledge          | Understanding of individual, community, national, and international efforts related to climate change |
|                    | Skills         | Scientific thinking          | Analytical and systemic thinking based on scientific logic                  |

Table 1: Content analysis framework for climate change education (CCE) (Park et al., 2020)
Aspects | Areas | Sub-areas | Description
---|---|---|---
Socioscientific reasoning | Climate justice | Recognizing climate inequalities and seeking equity
Reflexivity | Ecological perspective | Seeking harmony between humans and nature and recognizing equal values
Value and attitudes | Global citizenship | Recognizing identity and responsibility as a global citizen
Emotional and ethical empathy | Emotional and ethical empathy | Sympathizing with the conditions of disadvantaged groups for problems related to climate change
Practical aspects and action | Planning actions | Preparing actions in indirect contexts (e.g., investigation through the internet and books)
| Online | Authentic | Preparing actions in practical contexts (e.g., observation, measurement, and interview)
| Doing actions | Personal | Action on climate change at the personal level
| Socio-political | Socio-political | Action on climate change at the socio-political level

Park et al.’s (2020) CCE framework was derived by analyzing existing climate change education programs and includes knowledge, skills, values and attitudes, participation, and practices. Using the CCE framework, researchers and teachers mapped the Grade 6 related climate education content to develop a series of SSIBL-STEAM lessons aimed at constructing a balanced and comprehensive program that includes scientific exploration and social practice (see Table 2).
| Subject (number of classes) | National Curriculum Content | STEAM activity theme | SSIBL stage |
|-----------------------------|-----------------------------|----------------------|-------------|
| Social Studies (1)          | Find out about various environmental issues in the global community. | Ⓝ Understand the definition, cause, and effect of climate change | ⓃⒺ Find what we can do ourselves to respond to climate change |
| Science (4)                 | Understand ecosystem components. Investigate the effects of environmental pollution on living things. | ⓃⒶ Search and share information about climate change | ⓃⒺ Find what we can do ourselves to respond to climate change Ask |
| Korean (8)                  | Read resources (such as news, advertisements, books) to become interested in environmental issues, sorting and recalling content, comparing one's thoughts, and judging the validity and appropriateness of an argument. | ⓃⒶ Search and share information about climate change | ⓃⒶ Search and share information about climate change Ask |
| Ethics (2)                  | Learn about efforts to solve global problems, recognize environmental problems, and set topics to explore. | ⓃⒶ Search and share information about climate change | ⓃⒶ Search and share information about climate change Ask |
| Social Studies (2)          | Explore efforts to address climate change issues. | ⓃⒶ Search and share information about climate change | ⓃⒶ Search and share information about climate change Ask |
| Science (1)                 | Discuss how to use and save electricity safely. | ⓃⒶ Search and share information about climate change | ⓃⒶ Search and share information about climate change Ask |
| Korean (9)                  | Learn how to collect and evaluate data, compare one's thoughts with others, use data to speak and write arguments, and speak and write arguments with valid grounds and appropriate expressions. | ⓃⒶ Search and share information about climate change | ⓃⒶ Search and share information about climate change Ask |

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| Subject (number of classes) | National Curriculum Content | STEAM activity theme | SSIBL stage |
|-----------------------------|-----------------------------|----------------------|-------------|
| Practical Arts (1)          | Learn how to eat while thinking about the environment. | ☐ Express and share action plans in various ways |
| Ethics (2)                  | Plan to solve the topic of an inquiry and discuss the causes and solutions of climate change problems. | ☐ | |
| Science (5)                 | Campaign to cope with climate change, investigate and announce energy use in our school. | ☐ ☐ ☐ | |
| Social studies (1)          | Do what we can as global citizens. | ☐ ☐ ☐ ☐ | |
| Korean (8)                  | Write action measures for responding to climate change and make and present data on the results of practice in various ways (such as video and news articles). | ☐ ☐ ☐ ☐ | |
| Practical Arts (3)          | Practice eating habits that consider the environment, and practice and evaluate ways to save electricity at home. | ☐ ☐ ☐ ☐ | |
| Ethics (4)                  | Practice ways to solve climate change, perform and check inquiry tasks, and present and organize inquiry results. | ☐ ☐ ☐ ☐ | |
3.3 Data Collection

3.3.1 Research Context and Participants

In order to determine the impact of the climate change SSIBL-STEAM program on elementary school students’ character and STEAM key competencies, the teachers and researchers developed 51 lessons that were flexibly implemented over a 12-week period from October 2019 to December 2019. The research site was an elementary school located in an area of Seoul where there are many parks, forests, and streams so that lessons could be taught indoors and outdoors. A total of 80 Grade 6 students were enrolled, but only one class of 25 students completed the pilot program which this study reports.

The lessons were initially planned to be implemented in three Grade 6 classrooms by veteran elementary teachers with more than 15 years of teaching experience who all majored in either science or environmental education. The teachers were all members of a professional learning community who had worked with the researchers to develop the climate change SSIBL-STEAM program. The lead teacher (first author) is an environmental education major who organized the professional learning community with two other teachers who both had interest and experience in climate change education and who had experience developing curriculum. All of the teachers received extensive training to instruct students using a method called World Café (Brown & Isaacs, 1995). World Café is a popular approach for gathering information through structured group discussions to produce positive organizational change (Aldred, 2011; Jang, 2012). A World Café is a conversation where at least 12 people develop and share ideas in conversations started with 4–5 people that then move to other groups to cross-share.

This strategy helps teachers to facilitate students’ discussions during the SSIBL-STEAM lessons. The World Café training took place in the school and teachers also learned about STEAM teaching. The teachers met to discuss the lessons to be implemented. Through regular meetings before, during, and after class, the teachers shared their feedback and insights about the newly developed climate change -STEAM curriculum that would be implemented using SSIBL-STEAM lessons. However, after the three teachers began piloting the lessons, two of the teachers felt overburdened due to a lack of experience in climate change education and SS1s education, so two teachers decided to pause the pilot program and continue to support the implementation of the lessons in only the lead teacher’s class. The teachers continued to meet and discuss the lesson implementation of climate change education programs two to three times a week where they participated in observing and sharing feedback on students’ learning.
3.3.2 Research Instruments

In order to measure the impact of the lessons on different aspects of the students’ character, some items were extracted and used from Chi et al.’s (2014) Character Index Instrument designed to measure morality (honesty, responsibility, and compliance), sociality (sympathy, communication, and service), and emotion (self-understanding, self-esteem, and self-regulation). Each area contained 20 items. The Character Index Instrument has been previously implemented and validated with students in elementary, middle, and high school. For this study, 30 items suitable for elementary school students were extracted: morality (12), sociality (12), and emotion (9) used with a 4-point Likert scale response (4 points = strongly agree to 1 point = strongly disagree). Validity and reliability of previous use of the items (see Chi et al., 2014) with elementary age students were reported as 0.915 for sociality, 0.906 for morality, 0.864 for emotion, and 0.954 for total reliability.

To measure STEAM key competencies, we used the Instrument for STEAM Education Key Competencies developed by Park et al. (2019). The Instrument for STEAM Education Key Competencies was previously used with elementary, middle, and high school students and has been found to be valid and reliable. The instrument consisted of 32 questions in four domains: convergence, creativity, challenge, and care used with a 4-point Likert scale response (4 points = strongly agree to 1 point = strongly disagree). The reliability of the instrument for elementary and secondary school students (Park et al., 2019) was reported as 0.924 for convergence, 0.929 for creativity (problem-solving), 0.849 for challenge, 0.929 for consideration, and 0.965 for total. Subcategories and specific items used from each instrument are reported in Tables A1 and A2.

3.4 Analysis

To verify the effectiveness of the implemented program, pre-and post-tests were conducted with the same test paper before and after the program’s application. A total of 47 questionnaires were collected from 24 people in the pre-survey and 23 in the post-survey. However, only 42 (21 pretest and 21 posttest) were used for the final analysis due to incomplete answers. The mean and standard deviation were obtained using SPSS 25.0, and a corresponding sample t-test was used to compare the pre-and post-tests of the group.

This study has limitations in interpreting the results in that both tests are self-report data from elementary school students in a single classroom. To compensate for this limitation, we collected teachers’ class observation notes, memos, and records of consultations, and all data were qualitatively analyzed during the 12-week implementation phase. We can understand surveys more
holistically and derive requirements and improvements for program execution from qualitative data. In order to protect the identities of all participants, pseudonyms were used in reporting qualitative findings in the results section.

4 Results

4.1 SSIBL-STEAM Education Program for Climate Change in Elementary School

Based on the SSIBL instructional model, three sixth-grade teachers developed an educational program to implement climate change education in the national curriculum by combining various subjects in STEAM education. Table 3 shows the step-by-step activities of the climate change SSIBL-STEAM

| Stage | Content | Number of classes |
|-------|---------|------------------|
| Ask   | Ⓟ Understanding the definition, cause, and effect of climate change | 5 |
| Subtopics selected | ⓅⒺ Finding what we can do ourselves to respond to climate change | |
| Group 1. Saving electric energy | ⓇⒶ Selecting a specified subtopic and developing it as an authentic question. | |
| Group 2. Reducing trash (disposable items) | – What can we do to respond to climate change? | 6 |
| Group 3. Reducing remaining food (e.g., school meals, milk, et al.) | – What can we do to make a real plan? | 6 |
| Group 4. Promoting recycling (e.g., making video clip) | | |
| Group 5. Training for proper recycling | | |
| Group 6. Toothbrush recycling campaign with TerraCycle* | | |

* A global recycling consulting firm that creates new value for waste to solve environmental problems. Retrieved 02/20/2022 from https://www.terracycle.com/ko-KR.
### TABLE 3  Climate change SSIBL-STEAM program (cont.)

**Goal:** Finding and doing actions that we can do to respond to climate change

| Stage | Content | Number of classes |
|-------|---------|-------------------|
| Find out | ⓅⒶ Searching and sharing information about climate change- (Information search and research) Collecting information and data to solve selected questions  
- How to save electricity, problems related to waste in society, how to separate and dispose of waste, the current status of waste disposal at our school (home), the amount and cost of waste in our homes and schools.  
Ⓜ Calculating how much energy we use every day at home and school  
- How much is your electricity bill per month?  
ⓉⒺ Planning for problem solving and decision making  
- (Survey) Gathering surrounding conditions, information, and opinions  
e.g., Do you know how to separate waste?  
How often do you use disposables? Are you eating well?  
- (Recurring discussion) sharing information, sharing opinions, establishing practices and rules, and arguing  
- Activity methods, planning and decision making, public relations and guidance methods, prediction and reasoning of results, debates, finding ideas to reduce waste, and setting class practice rules together  
Ⓐ Expressing and sharing action plans in various ways  
e.g., posters, writing, presentations, pictures, videos, webtoons. | 4 |
| Act | ⓅⒺ Review the plan and implement it together  
ⓉⒺ If we face obstacles, then go back to Ask stage  
- (Action results) Turn off and unplug unused lights in the classroom and at home, wear warm layers reduce garbage (restrict the use of disposable products), properly separate garbage and dispose of it (school, home), do not waste school meals. | 18 |
Goal: Finding and doing actions that we can do to respond to climate change

| Stage | Content | Number of classes |
|-------|---------|------------------|
| – (Education and promotion) Education about separation of waste for lower grades, UCC and quiz competition to promote separation of garbage, production, and pasting of posters to promote waste reduction, and holding a toothbrush recycling campaign in school | | |
| ₋ Sharing challenges we have met during the implementation | 1 |
| ⓆⒶ Mini-conference activity for sharing results, feedback, and reflections. | 2 |
| – Sharing the activity process, practice results, and feelings during the presentation | |

Note: The letters ⓈⓉⒺⒶⓂ in the table refer to science, technology, engineering, arts, and mathematics, respectively.

education program, which reconstructed the second semester of Grade 6 2015 revised curriculum using the SSIBL instructional model. It took approximately 40 minutes for each of the 51 lessons to be implemented.

The SSIBL-STEAM education program was developed and implemented to consider the following points. First, the main activity in the Ask stage was for students to find the actual problems in their lives that involve climate change based on their understanding of climate change. Raising authentic questions and connecting with various subjects with somewhat complex are critical which can be the starting point of education that stimulates students’ interest. In order to find problems, students started lessons with a unit called “Learning about various environmental problems that occur in (social) global villages.”

Focusing on climate change among various environmental problems, students came to understand the seriousness and risk of climate change and learned about the connection between climate change and lifestyle. Each student had different experiences and was interested in different problems, so the students formed small groups based on climate change phenomena that they felt particularly serious about. The teacher provided each group with
a question checklist called the “The Question Machine” (Figure 3),¹ which helped students specify problems on their own and to formulate abstract topics into practical questions. Each small group selected one of six subtopics: saving electric energy, recycling hard-to-recycle items, learning about recycling methods, promoting recycling, reducing food waste, and reducing use of disposable plastic (see Figure 4).

During the Find Out stage, students found solutions to practical problems and prepared for practice. Mostly scientific exploration activities were carried out, such as collecting and checking data necessary for problem-solving and finding solutions. In order to find a solution suitable for their practical problems, students collected information through books and web searches. All activities were carried out within regular school hours using wireless-enabled classroom tablets provided to students. The information found by students

¹ The Science Education Hub Radboud University in the Netherlands also offers worksheet for the question machine activities: https://www.ru.nl/wetenschapsknooppunt/english/materials/.
was shared using a sharing platform called Linoit² which allowed students to make web memo books. In addition, since different students had different topics, whole-class discussion time was held at least twice a week so that they could learn about each other’s activities and share opinions. Although activities were carried out during lessons in school as much as possible, some activities were also carried out during after-school hours at local community centers or homes, depending on the students’ activities (e.g., conducting surveys or field visits). As the activities progressed, students became interested in other students’ topics so they were encouraged to link and combine their projects (e.g., reducing waste and participating in toothbrush recycling campaigns). Figure 5 offers some examples of student activities.

The teacher who enacted this program said that the lesson at this stage was the most difficult to guide because students had little experience finding solutions to problems themselves. In addition, the teacher suggested some areas for improvement, including having students present first to formalize and present their ideas about their specific plans to solve problems before engaging in various investigations. Next, as students’ educational activities are conducted within the curriculum, the program’s content, speed, and methods need to be adjusted to better consider the classroom context. Finally, the World Café activities need to be scheduled more frequently so students can regularly share

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² ‘Linoit’ is a free web memo platform used for sharing ideas: https://ko.linoit.com/.
information and opinions, deal with conflicts of opinions, and make decisions. The teacher felt the unique structure of the World Café, which connects small intimate conversations and ideas to larger networks so they can think creatively together was positive for students’ problem-solving.

In the Act stage students work to find solutions by building practical knowledge about the problem, and then feeling and understanding what changes occur through modification and practice (see Figure 6).

In this stage, students engaged in activities directly in schools, homes, and communities to solve the problems they found and sometimes revised and identified new information about problems. For example, after conducting a separate waste collection campaign and realizing that the different collection criteria were confusing, students returned to the Ask stage to go through an inquiry process again to re-organize criteria for items group members found to be particularly confusing in the Find Out stage. Conflicts between some students in the practice process were resolved by teachers and students discussing together to create and agree on new rules. In addition, through the practice process, activities changed into more practical and effective practices than planned, such as volunteering to provide separate waste discharge education to lower grade students, making separate waste discharge video clips, and making toothbrush recycling promotional posters. At the presentation of the
Figure 6  Examples of Act stage activities. Campaign and promotion events: (a) how to classify trash, (b) no food left behind lunch (NFLB), (c) Why should we join recycle, (d) collaboration activity with NFLB and farmer’s day (Nov. 11), (e) waste toothbrush mailbox, and (f) sending toothbrush box to recycle company.

final results, which presents students’ practical experiences, many students expressed a sense of satisfaction with their outcomes. Some students reported that they realized that there was a limit to what they could do about climate change. The perception that the cooperation of companies, governments, and adults can be more practical in solving the climate change problem is expected to be the seed of democratic citizenship education.

4.2 Effects of the Climate Change SSIBL-STEAM Education Program

4.2.1 Aspects of Character

Table 4 shows the results of the corresponding sample t-test with scores before and after class to explore the effect of the SSIBL-STEAM climate change program on elementary school students’ character related to sociality, morality, and emotion. Morality refers to the ability to recognize and judge core values in ethical situations and to implement responsible behavior. Sociality refers to understanding, maintaining, and communicating positively with others. Emotion
Table 4  Pre- and post-test comparisons of students' character

| Area (number of items) | Pre-test | Post-test | t   | p    |
|------------------------|----------|-----------|-----|------|
|                        | M        | SD        | 4-Avg | M    | SD  | 4-Avg |
| Sociability (9)        | 27.05    | 3.057     | 3.01 | 27.71 | 3.452 | 3.08  | -0.639 | 0.530 |
| Morality (12)          | 35.24    | 3.632     | 2.94 | 38.62 | 4.177 | 3.22  | -2.545 | 0.019* |
| Emotions (9)           | 28.57    | 3.993     | 3.17 | 30.48 | 3.156 | 3.39  | -2.149 | 0.044* |
| Total (30)             | 90.86    | 5.416     | 3.02 | 96.81 | 6.104 | 3.23  | -4.550 | 0.000** |

*p < 0.05, **p < 0.01, M: mean value of survey, SD: standard deviation, 4-Avg: four points conversion average

refers to controlling emotions and behaviors to achieve one's goals (Chi et al., 2014). On average, students' character measures improved from 90.86 to 96.81, and there was a statistically significant difference (p < .01). While the mean improved in all subareas of character, there were statistically significant differences only in morality and emotion.

In the case of sociality, the post-test results improved from 27.05 points to 27.71 points, but there was no statistically significant difference. Sociality's subfactors are sympathy, communication, and service. This result indicates that students cooperated with their friends through climate change lessons, but may have lacked the internalization necessary for sympathizing with people's difficulties living in other regions. This change is also supported by the response to each question and the results of class activities. Students tended to have lower post-scores on the questions “I want to help if I have a friend who does not get along well” (service, # 4) and “I am worried if my friend looks depressed” (sympathy, # 8). In addition, at the presentation of the results of the activities at the end of the class, students were skeptical about empathy for people suffering from climate change, communication with them, and service consciousness. The following are some of the students' responses.

I feel sorry for people suffering from climate change, but I honestly do not know how hard it is because I have not experienced it.

JI-A, 11

I want to help people affected by climate change, but I need to ask how I can help them because no one is around me [affected]. Efforts to cope with climate change are not visible.

BYOUNG-HO, 11
As I keep seeing people struggling with climate change, I know it is hard, but I am not sure what climate change will do right away tomorrow. I am worried and not worried at the same time.

EUN-SU, 11

In order to improve the SSIBL-STEAM program based on these results, it will be necessary to discuss internalization methods that help students reflect on themselves during the class or after the program. Moreover, since immediate change is not visible even when practicing climate change, students will also need to have internal empathy, communication, and dialogue to praise and encourage their actions together.

On the other hand, there was a statistically significant improvement in morality (honesty, responsibility, and ethics) from 35.24 to 38.62 points and in emotions from 28.57 to 30.48 points. Morality had the most significant change, increasing on average from 2.94 to 3.22. It can be seen that the climate change SSIBL-STEAM program empowered a change in morality in the process of moral judgment and reasoning on the issue. Students’ awareness of morality has increased in predicting the results and problems of honesty, responsibility, and compliance from the perspective of those who suffer from the development of technology and climate change caused by fossil fuels in class. In addition, the change of emotions (positive understanding of oneself, self-emotion control) seems to have been influenced by many opportunities for self-understanding, self-esteem, and self-regulation in understanding, expressing, and acting to friends during the program. This change is also supported by individual item responses and the results of class activities. For example, items like “I have a responsibility to protect everything that is alive” (responsibility, # 16) and “I try to understand a friend even if they have a different idea from me (self-regulation, # 30) showed the most change in the post-test. At the presentation of the results of the last activity, some students were aware the damage caused by climate change could be done not only to humans but also to animals and plants and they felt their responsibility as future inhabitants of the planet. During the whole program, the students’ thoughts and methods of practice were different, but they showed an attitude of understanding and respected their friends’ opinions. The following are some of the students’ responses.

I think the responsibility for climate change lies with us and everyone who lives now.

JAE-MIN, 11
Since life is precious to all the animals, plants, and people on this planet, wouldn't it make everyone happy if we stopped climate change?

YUN-JI, 11

I had a hard time because my friends and I had very different opinions on stopping and acting on climate change. However, we might think differently, so we talked a lot and tried to find a middle ground.

SEUNG-HYUK, 11

People may think differently. The people who cause climate change and the people who prevent climate change have different ideas, and we had different thoughts in this class. However, when we talked together, it felt much easier and more like the right decision than when we solved a problem ourselves.

MIN-SEOK, 11

The above was influential in the development of character overall, and there was a significant effect on morality and emotion, which are sub-elements, but there was no significant difference in sociality. The SSIBL-STEAM lessons go beyond being interested in climate change topics, empathizing from various perspectives, and preparing and practicing for solutions to cope with climate change. In the actual lessons, students sympathized with people in need due to climate change and communicated and cooperated with friends for solutions. The teacher who conducted the lessons was also aware of the strong effect. From this, it seemed that the effectiveness of the program was perceived differently by students and teachers. This result supported previous studies about the effectiveness of characteristics emphasizing ethical aspects such as character and emotion in SSI education and in the area of social and moral empathy of elementary, middle, and college students (Ko & Lee, 2017; Kim et al., 2016; Kim et al., 2015; Park et al., 2018), and moral sensitivity of high school students (Sadler, 2009).

4.2.2 Aspects of STEAM Key Competencies

Changes in STEAM key competencies of elementary school students were measured to determine the effectiveness of the program. The results show that after the program's application, the average STEAM key competencies improved from 92.48 to 97.95, and there were statistically significant differences to report ($p < .05$; Table 5). In the subareas of STEAM key competencies, the average of convergence, challenge, and care improved, but there was
Table 5 Pre- and post-test comparisons of STEAM key competencies

| Area (number of items) | Pre-test | Post-test | \( t \) | \( p \) |
|------------------------|----------|-----------|--------|------|
|                        | M        | SD        | 4-Avg  | M    | SD | 4-Avg  |        |      |
| Convergence (7)        | 20.52    | 2.713     | 2.93   | 24.71| 3.608 | 3.53   | -5.697 | 0.000** |
| Creativity (11)        | 30.57    | 5.912     | 2.78   | 29.71| 5.293 | 2.70   | 0.529  | 0.603  |
| Challenge (5)          | 14.43    | 3.026     | 2.89   | 15.52| 3.100 | 3.10   | -2.001 | 0.059  |
| Care (9)               | 26.95    | 4.105     | 2.99   | 28.71| 3.926 | 3.19   | -2.065 | 0.052  |
| Total (32)             | 92.48    | 12.452    | 2.89   | 97.95| 12.488| 3.06   | -2.864 | 0.010* |

\( *p < 0.05, **p < 0.01, M: \) mean value of survey, SD: standard deviation, 4-Avg: four points convergence average

A statistically significant difference only in convergence (\( p < .01 \)). On the other hand, the average for creativity slightly decreased from 30.57 to 29.71.

Although there was no statistically significant difference between challenge and care competencies, the average was improved. Challenge is the ability to willingly try new situations and trial and error that must be encountered when exploring and practicing open problems without answers. In participating in this program, a particularly challenging issue for students was decision-making. Even though students formed a small group with similar interests, they faced conflicts or complex decision-making due to different opinions in planning and implementing specific solutions. Initially, the problem was solved by the teacher’s intervention. However, the students gradually understood other people and resolved the conflict according to their own rules through good conversation or persuasion activities. This shows the improvement of the care competency at the same time. Care is the ability to understand the position of others and perform cooperative communication. In particular, students experienced the power of communication to create a better alternative by collecting different opinions while repeatedly participating in the World Café discussion and the whole-class discussion. Furthermore, differences in opinions and conflicts were recognized as natural and resolvable situations. This phenomenon improved communication efficacy. It was also linked to convergence compliance, listening to and accepting feedback from friends from other subject groups, and becoming the driving force behind the emergence of new convergence projects.

This change was also supported by individual item responses and the results of class activities. Students had the most changes in post-test questions in the
challenge and care section: “I am not afraid of failure when I do what I want” (#23), “I am willing to spend my time and resources on people in need.” (#28), and “I try to understand other people’s feelings” (#27). At the final activity results presentation in class, students did not hesitate to inform many people when they acted to solve the problem of climate change, although the results were not immediately clear. They also responded that even if the climate change problem is not solved, it is rewarding for them to participate in such climate change response actions. Students learned how to respect and compromise different opinions, although there was friction in deciding how to tackle climate change. The results also show that students tried to understand each other’s feelings. The following are some of the students’ responses.

I liked the action I decided to take in response to climate change. Although the other group members seemed to do better, I liked how I decided to act.

SUN-JAE, 11

I would not have wanted to do what I wanted, but I did it the way I thought it was most effective, so I worked harder, and it was fun regardless of the results.

MI-NA, 11

When we first discussed, we disagreed, so we fought while talking, but I think it was more fun to talk about persuading them because they had different ideas.

SEUNG-HYUK, 11

The convergence competency that students reported as the most improved competency was creating new things by mixing several fields, topics, or tools. Through repeated discussions, students recognized that similar or connected activities form activities associated with each other to solve climate change problems. Climate change problems are related to each other, and it is easier to cooperate with others. As a result, in the exploration, different groups with topics such as reducing waste and recycling toothbrushes naturally united to conduct joint campaigns and collaborate on farmers’ day events and their projects. In this process, students expressed that they came up with solutions to the climate change problem by connecting and responding together.

This change is also supported by individual item responses and the results of class activities. For example, the items “today, it is essential for students to think connectedly about the content of various subjects” (# 1) and “I use
knowledge of various subjects to solve problems in real life" (# 8) in the challenge area changed the most in the post-examination. At the presentation of the results of the last activity of the class, students answered that climate change classes are most effective in understanding climate change, finding problems, and practicing when thinking about various subjects together. In addition, to solve a problem well, students felt that it was adequate to connect and use knowledge of various subjects. The following are some of the students’ responses.

To solve the problem of climate change, you must be good at science, and you must be good at math, morality, and the Korean language of writing or the art of poster drawing when promoting.

SUN-JAE, 11

It was boring if I learned just a single subject one by one. But during this STEAM class, I should find various information related to the theme as much as I needed no matter what subjects freely, and it was fun and good.

MI-NA, 11

In the STEAM Education Key Competencies instrument, the creativity competency includes the ability to produce new and original ideas and solve problems, and this section contains the highest number of test questions. Previous studies showed that students who experienced STEAM lessons were significantly higher in all four competencies than those who had not had STEAM lessons (Park et al., 2019). However, students who participated in the SSIBL-STEAM program did not have significant creativity capabilities, with their scores falling slightly. Looking at the results of qualitative data analysis, it appears that both students and teachers recognized that their problem-solving skills had improved. By finding necessary information, sharing knowledge and experience, and explaining these to friends while participating in the program, they could increase their understanding of the relationship between life phenomena and climate change and express their thoughts in detail.

This change was also supported by the response to each question and the results of class activities. In the questions “I practice the solution I set in detail according to the plan” (#13) and “I reasonably express my opinion to persuade other friends well” (#17), the post-score tended to fall. In addition, at the final activity results presentation, students responded that it was challenging to plan and implement in detail because their plans kept changing during the program, and they experienced climate change response actions. Students said
that they persuaded their friends, but they seemed to accept all the opinions that were presented out of respect for their friends.

Looking at the results of their impressions of the class, both students and teachers perceived that their problem-solving skills had improved. By finding necessary information, sharing knowledge and experience, and explaining these to friends during the program, they improved their understanding of the relationship between life phenomena and climate change and were able to express their thoughts in detail. Nevertheless, for the survey conducted after the end of the program, two factors may have caused decreases in the creativity area. First, students may have felt somewhat bored and their motivation decreased after performing a long-term program with one theme. This is in line with the research results that show that individual fatigue or discomfort hinders creativity (Jeon, 2000) and that students' intrinsic motivation for learning affects creativity (Lee & Min, 2013). Another reason may be the decrease in confidence in problem-solving ability due to students feeling somewhat concerned for the results of social practice in the practice stage.

Students practiced climate change response behavior personally and socially and saw that it could affect people around them but recognized that their activities had limitations. In order to expand the scope and target of activities, students practiced campaign activities on campus, did promotional and practical activities in their neighborhood, and made suggestions to local institutions. In this process, elementary school students felt the limitations of their practice and influence. According to a study by Lim et al. (2021), elementary school students are not interested in social problems or are limited in their ability to make real and meaningful voices to solve them. However, the toothbrush recycling campaign linked to a social company caused a positive response in students’ understanding of resource circulation and corporate social responsibility. Therefore, finding ways to help students feel their significant influence is necessary, including activities to link climate change education.

5 Conclusion

We can draw three conclusions drawn based on the results and discussions of this study. First, the SSIBL instructional model was successfully adapted to Korean educational contexts and the SSIBL’s three-stage teaching model was found to be a systematic and easy-to-apply teaching model, even for teachers new to SSIS education (Amos & Levinson, 2019). The three stages, Ask, Find Out, and Act, present specific content that students can do step by step and
were particularly effective for learning action-oriented climate change education. In addition, the SSIBL class model was found to ease the burden on teachers for SSIs classes by presenting the order and method of classes for teachers.

Second, the results suggest the possibility that STEAM education can contribute to the spread of SSIs education. SSIs education effectively cultivates convergence capabilities of STEAM key competencies and is in line with the convergence thinking pursued by STEAM education and the integration and linkage between subjects. STEAM education has a lot of research and support in terms of national policy and has become more common in school sites, and research is continuing to be done that centers on teacher research groups. The research and application of SSIs education in elementary schools could be further activated in connection with this. Nevertheless, we need more theoretical effort to articulate the connection between SSIs and STEAM to expand possibilities.

Third, SSIs education has effectively cultivated the study of character that has been pursued in school education, and the possibility of character education through climate change education seems promising. SSIs include pure scientific content, application aspects of scientific knowledge, and humanities and sociological aspects such as society, politics, and economy. SSIs can be used as an educational method that can expand the scope of science education through SSIs education and cultivate character in school education where character cultivation is emphasized. We expect that SSIs education programs on various topics, including climate change, will be developed and applied in the school field and used for character and various educational effects.

This study suggested a direction for implementing action-oriented climate change education in the context of the new 2022 revised national curriculum in Korea. There may be concerns and confusion about performing action-oriented climate change education in schools. This study offered good examples of various efforts and attempts to perform action-oriented climate change education linked to subject classes and climate change education linked to STEAM education. For teachers’ actual enactment, it is essential that teachers’ have professionalism, active participation, and interest in climate change education.

6 Discussion

This study developed the SSIBL-STEAM education program for elementary school students based on the SSIBL class model developed by the PARRISE project. The curriculum for the second semester of sixth grade in the 2015 revised curriculum was reorganized around a climate change issue (MOE, 2015).
The Character Index and STEAM key competencies of 21 Grade 6 students were measured and compared before and after the program. In addition, to determine the effect of the curriculum application, the perception of the effect of key competencies was analyzed based on the feelings of students and teachers, class observation, and memos. The summary of the research results is as follows.

First, SSIs and STEAM education research in elementary schools were in different context. An analysis of SSIs education research subjects in Korea showed that there has been much less research on elementary school students than on other groups (Seo, 2020). One reason for this may be found in Jho (2015), who showed that SSIs education was somewhat challenging to apply at the elementary school level. On the other hand, STEAM education is widely conducted in elementary schools in Korea. Convergence of subjects is easier in elementary schools where most of the subjects are handled by homeroom teachers. Studies have shown that the use of SSIs education has increased over the past decade to improve STEM curriculums and outcomes (Alcaraz-Dominguez & Barajas, 2021). Based on this, the possibility of classes linked to STEAM education can be found as a way to activate SSIs classes in elementary schools.

Second, this study confirmed that the value of STEAM education and SSIs education could be linked through the SSIBL-STEAM program developed by converging and reorganizing various subjects. SSIBL education is another adaptation of inquiry-based learning to the context of SSIs combined with civic education (Romero-Arizas et al., 2017). This study, which developed and applied SSIBL-STEAM classes linked to the SSIBL class model, could be the basis for showing that SSIs education can be sufficiently implemented in elementary schools.

Third, the climate change SSIBL-STEAM program was effective in cultivating character. Since the concept of the character itself is unclear and different definitions are often used depending on the subject of inspection and the educational environment, the most crucial task in developing a character test tool is to define the concept of character. The concept of character as defined and examined in this study aims to classify character factors based on the three dimensions of character suggested by the Ministry of Education, Science, and Technology3 (currently the Ministry of Education), and questions were prepared for each dimension. This study also used a Character Index Instrument developed by Korean teachers and character education experts (Chi et al., 2014). Meanwhile, many existing SSIs education studies have

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3 The name of the government agency changed from the Ministry of Education, Science, and Technology to the Ministry of Education in 2013.
identified the character and effectiveness of certain areas closely related to SSI, such as science and science-related issues; ecological worldview; social and moral empathy (Lee et al., 2013; Ko & Lee, 2017; Kim et al., 2016; Park et al., 2018). Besides, this study showed that the program influenced to personal character such as morality, sociality, and emotions positively. This results indicate that the SSIBL-STEAM program can be used as a new method of character education in elementary schools.

Fourth, the SSIBL-STEAM program effectively cultivated STEAM key competencies by participating in the climate change issues. For example, the research results of applying classes in connection with SSI education and STEAM education enabled the examination of students’ climate literacy and teachers’ practical knowledge (Won et al., 2021; Choi et al., 2021). As a good example of linking SSI and STEAM education, this study examined the effectiveness of STEAM education from an integrated perspective of creativity, communication, convergence, and consideration, which are STEAM key competencies. In particular, it was effective in cultivating convergence capabilities because the subfactors of understanding and utilization and application capabilities of convergence knowledge, convergence design capabilities, and contextual understanding, are in line with the convergence nature of the climate change SSI program. On the other hand, there was a slight decrease in creativity competency, including problem-solving ability, which seems to have been a factor due to decreased motivation due to long-term program performance. It is necessary to summarize the above research results and identify the requirements for improving the developed climate change SSIBL-STEAM program and reflect them in future educational activities and research.

7 Implications for Future Research

The first issue is teacher expertise. In this study, the teacher leading the program had 15 years of teaching experience, had experience developing curriculum, had completed professional development several courses in facilitating discussion and debates, and had taken a couple of graduate classes on SSI. This teacher had experience in STEAM teacher research association activities and was one of the professionals who conducted this study. Nevertheless, this teacher reported that the program was challenging to implement and required a lot of expertise and effort to plan and implement the SSIBL-STEAM classes. Lim et al. (2021) also reported that it was difficult for elementary school teachers to run social action-oriented climate change club activity programs because it was challenging for teachers to understand and organize sporadically scattered climate change data alone. Therefore, to integrate various subjects and devise
and implement long-term project classes that run for more than a month, it is necessary to form teacher learning communities and proceed together. This will ease the burden on individual teachers and improve the quality of program performance by exerting collective intelligence.

Another issue is the curriculum system. In this study, to determine the applicability of educational programs conducted within curriculum class hours, the curriculum was reorganized, focusing on the achievement standards in the curriculum and the content of educational activities. However, there were parts where the content of the achievement standards and educational activities did not match the content of the necessary activities in the educational program. It was also a problem that the program was somewhat prolonged. In addition, although an attempt was made to perform as many activities as possible during class hours, students needed to perform after-school activities at home or in the neighborhood and then share them during class. Therefore, we believe that the development of educational programs that can utilize various times and places, such as club activities, hands-on learning, and curriculum classes, can lead to more diverse practices.

Finally, the application period of the SSIS program needs to be considered. The climate change SSIBL-STEAM education program reorganized five subjects and proceeded with 51 class hours over 12-weeks. However, the long-term application of the program had an unexpected disadvantage. Apart from the educational effect, in the second half of the program, some students became familiar with repeated discussions and activities but appeared to be somewhat bored. When developing a program for elementary school students in the future, content and activities and application periods need to be suitable for the grade level.

Abbreviations

| Abbreviation | Description |
|--------------|-------------|
| RRI          | Responsible Research and Innovation |
| SSIS         | Socioscientific Issues |
| SSIBL        | Socioscientific Inquiry-Based Learning |
| STEAM        | Science, Technology, Engineering, Art, and Mathematics |

Acknowledgments

We wish to express our gratitude to the teachers and students in Korea who participated in this study. We would also like to thank the anonymous reviewers for their helpful suggestions and feedback.
Funding

This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2019S1A5A203048062).

Ethical Consideration

Approval to conduct this study was granted by the Seoul National University Ethics Review Board (IRB No. 2006/001-012). The data collected from this project has obtained the necessary clearance from the school, guardians, and the students involved in the study. The names of the school and participants used in the article are all pseudonyms. Any photos and images appearing in this paper were provided with the permission of the participant.

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## Appendix

### Table A1  Character Index Instrument (from Chi et al., 2014) adapted from subcategories of sociality (1–9), morality (10–21), and emotion (22–30)

| Op | Item                                                                 | Op | Item                                                                                                                                 |
|----|----------------------------------------------------------------------|----|-------------------------------------------------------------------------------------------------------------------------------------|
| 1  | It is essential to be considerate of the weak.                      | 16 | We have a responsibility to protect everything that has life.                                                                      |
| 2  | It is not good to ostracize a friend at school.                     | 17 | I think homework should be submitted by the day the teacher told me.                                                               |
| 3  | I need to try to understand people in different environments.       | 18 | I take responsibility for my work.                                                                                                 |
| 4  | I want to help if I have a friend who does not get along well with others. | 19 | It is essential to be good to your parents.                                                                                       |
| 5  | I do not do volunteer work unless it helps me directly.            | 20 | When you see your elders, you should be polite and respectable.                                                                     |
| 6  | I help my physically challenged friend when they need help.         | 21 | I use honorifics when I talk to my elders.                                                                                         |
| 7  | It is essential to respect other people’s feelings.                | 22 | I know what I feel.                                                                                                               |
| 8  | I am worried if my friend looks depressed.                         | 23 | Everyone in the world has value.                                                                                                  |
| 9  | I comfort my friend when they are sad.                              | 24 | I think I am worth as much as anyone else.                                                                                         |
| 10 | It is essential to be honest.                                      | 25 | I can be a necessary person in society.                                                                                           |
| 11 | Everyone has to live with their conscience.                        | 26 | I know myself very well.                                                                                                          |
| 12 | Everyone should try to abide by the rules.                         | 27 | When something difficult happens, I try to think of the positive side.                                                           |
| 13 | I think it is okay not to stand in line during school lunchtime but to cut in in the middle. | 28 | It is terrible to take it out on someone else when angry.                                                                          |
| 14 | It is okay to jaywalk when you are busy crossing the street.       | 29 | I think you should actively participate in activities with your friends.                                                          |
| 15 | I lied to my parents a lot to not get scolded by them.              | 30 | I try to understand my friend even if they have a different idea from me.                                                         |
**Table A2** Instrument for STEAM Education Key Competencies items adapted (from Park et al., 2019) subcategories of convergence (1–7), creativity (8–18), challenge (19–23), and care (24–32)

| Op | Item                                                                 | Op | Item                                                                                                                                 |
|----|----------------------------------------------------------------------|----|-------------------------------------------------------------------------------------------------------------------------------------|
| 1  | Today, it is essential to think about the content of various subjects.| 17 | I am good at persuading other friends by expressing my opinions coherently.                                                        |
| 2  | It is necessary to learn the subjects learned at school by connecting them. | 18 | I actively express my thoughts to solve the problem.                                                                                 |
| 3  | When solving a problem, you should use knowledge from various subjects to solve the problem. | 19 | I like to try something new.                                                                                                         |
| 4  | I can solve the problem better by using my knowledge of various subjects. | 20 | I am not very conscious of other people’s views or evaluations.                                                                     |
| 5  | The use of convergence of knowledge and science and technology develops society. | 21 | I like new challenges, even if they are challenging, rather than being satisfied with the present.                                 |
| 6  | In order to solve problems that occur in real life, knowledge of various subjects is connected and used. | 22 | I take courage and try to do things for the first time.                                                                                |
| 7  | It is great to have a job that utilizes convergence knowledge.       | 23 | I am not afraid to fail when I do what I want.                                                                                       |
| 8  | I can think of an idea that no one else can think of.                | 24 | When I listen to other people’s opinions, and I try to understand their position.                                                   |
| 9  | I often hear from people around me that I have a lot of original thoughts. | 25 | I want to live by doing things that help others.                                                                                     |
| 10 | When I solve a problem, I present a new problem solution using the content of various subjects. | 26 | I like to work in cooperation with others.                                                                                           |
| 11 | I offer more solutions than friends when given a problem.           | 27 | I try to understand other people’s feelings.                                                                                         |
| 12 | I can choose the best solution from many ideas related to the problem. | 28 | I am willing to use my time and substance for people in need.                                                                       |
### Table A2  Instrument for STEAM Education Key Competencies items (cont.)

| Op | Item                                                                 | Op | Item                                                                 |
|----|----------------------------------------------------------------------|----|----------------------------------------------------------------------|
| 13 | I practice my solution in detail according to the plan.             | 29 | I also consider the position of other friends when I argue in class. |
| 14 | After solving the problem, I think again about how I solved the problem and found a point to fix. | 30 | I understand other people’s opinions well.                           |
| 15 | I collect information in various ways to solve problems.            | 31 | I communicate reasonably with my friends.                            |
| 16 | I easily express my learning results in pictures or writing.        | 32 | It is essential to exchange opinions with friends when doing group activities in class. |