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The Impacts of a Climate Change SSI-STEAM Program on Junior High School Students' Climate Literacy

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Abstract

This study aims to investigate climate literacy among junior high school students participating in an SSI-STEAM climate change education program and to examine the impacts of the program on the cultivation of climate literacy. Thirty-one eighth-grade students in Seoul, Korea, participated in this study. Data were collected using pre- and post-program surveys with a climate literacy questionnaire (CLQ), students' background survey questions, interviews with participants, and from the artifacts produced by students during the program. Participants' climate literacy was shown to improve substantially after attending the program, especially in the domains of perception and action. The four characteristics of climate literacy change were identified in the participants' responses: more concrete ideas, extension of the scope of thinking, positive responsibility, and relevance recognition. The climate literacy program developed showed potential for fostering young people's climate literacy along with their understanding of responsible national and global citizenship. The study discusses the implications of these findings and includes suggestions for future climate literacy program development and for both curricular and extra-curricular climate change education that can together nurture students' more profound understanding of climate change.

Keywords

climate change – SSI education – STEAM education – climate literacy

초록

이 연구의 목적은 학생들의 기후 소양 함양을 위해 개발된 기후변화 SSI-STEAM 프로그램의 효과를 확인하고, 프로그램에 참여한 중학생들의 기후 소양 변화의 특징을 이해하는 것이다. 연구 참여자는 중학교 2학년 학생 31 명이며, 자료 수집은 기후소양 검사지 (CLQ) 를 이용한 사전, 사후 검사, 학생 면담, 수업 활동지나 작품 등 산출물, 배경 설문 조사 등을 통해 이뤄졌다. 연구 결과, 본 프로그램에 참여한 학생들은 대체로 기후 소양이 향상되었으며, 특히 인식과 행동 영역에서 많이 향상되었다. 학생들의 기후 소양 변화의 특징은 “개념의 구체화”, “범위의 확장”, “긍정적 책임감”, “관련성 인지”의 네 가지로 나타났다. 기후 소양에 기반한 기후변화 SSI-STEAM 수업이 청소년의 실천적인 기후소양 시민의식 신장에 기여할 가능성을 보였다. 이 연구를 통한 기후소양에 대한 심층적 이해는 학교와 학교 밖 기후변화 프로그램 개발과 교육에 대한 시사점을 제공할 것이다.

1 Introduction

Currently, the threat of climate change has already had a direct impact on humanity. Some people have even suggested the term ‘climate crisis’ be used to highlight the threat and encourage the public to recognise its gravity and take action as responsible citizens willing to work to mitigate the climate crisis (Paglia, 2018). Global warming, which is one aspect of climate change, has caused melting icebergs, sea-level rises, and a higher frequency of extreme weather events such as scorching heat and prolonged monsoon seasons. The unstable climate is a crucial factor in creating unexpected volatility in the industry most directly related to our survival: agriculture (IPCC, 2018, p. 41). The effects of the greenhouse gases that have already emerged will last at least 100 years. Therefore, climate change affects all adult members of society, including students, the adults of the future. (Yoon, 2009). Many researchers have emphasised that climate change education is the key to future generations taking control of this problem as the chief stakeholders in this planet’s survival (Anderson, 2012; Busch et al., 2019; Cantell et al., 2019; Monroe et al., 2019; Reid, 2019; Rousell & Cutter-Mackenzie-Knowles, 2020). This is the justification for the current global interest and calls for the promotion of a broader climate-literate public (Arndt & LaDue, 2008).

A climate-literate citizen is ‘able to make informed and responsible decisions concerning actions that may affect climate’ (USGCRP, 2009, p. 4). Milěř and Sládek (2011) argued that fostering climate literacy is essential for the sake of future generations. Kim and Choi (2010) suggested the need to establish guidelines for climate change education, using phrases such as ‘climate change literacy’. Climate literacy is in line with science literacy (Azevedo & Marques, 2017), which is one of the purposes of socio-scientific issues (SSI) education. Addressing climate change issues with an SSI educational approach can help students make decisions about climate change and participate in climate change response action. A few SSI education studies related to climate change have been conducted in Korea (Jang et al., 2012; Kim et al., 2015; Kim et al., 2018; Park et al., 2018). Zeidler et al. (2005) suggested that SSI education improves scientific literacy and so assists problem-solving concerning complicated environmental issues such as climate change. Climate change education and climate literacy tend to converge where science, technology, society, humanities, and the arts are intertwined. We suggest that the convergent STEAM educational approach can be linked to climate change education in that it emphasises intersection or convergence as a valuable tool to deal with content.

As climate change has become a more serious issue, climate literacy inevitably has attracted attention as a particular area of interest within science

literacy (Dupigny-Giroux, 2010). ‘Climate literacy’ is still a relatively new term compared with other forms of science-related literacy (Miléř, & Sládek, 2011). Despite many published reviews and case studies on the definition and constituent elements of climate literacy (Arndt & LaDue, 2008; Azevedo & Marques, 2017; Beck et al., 2013; Lee, 2012; Park, 2013,) more empirical case studies in sufficiently diverse contexts are still required to enact and expand climate literacy in the educational field.

This study aims to explore whether an action-oriented SSI-STEAM approach in climate change education might be an appropriate educational tool for fostering climate literacy. A climate change SSI-STEAM program integrating climate change education has been shown to improve students’ climate literacy and to encourage convergent thinking, creativity, communication, and problem-solving skills. (Lee et al., 2013; Madden et al., 2013). The program also aims to raise students’ social and moral empathy capabilities, a potential already noted in SSI education. Specifically, our research aims to contribute fresh insight and to act as a mixed-methods case study of the SSI-STEAM approach, including its context and content, with its focus on how climate literacy can be improved and what characteristics may emerge from that improvement. The major goal of this study is the investigation of participants’ changed climate literacy; other objectives are the clarification of the concept of climate literacy and the development of an SSI-STEAM educational program to foster climate literacy. To achieve this, we set two research questions:

- (1) What are the impacts of a climate change SSI-STEAM program on junior high school students’ climate literacy?
- (2) What are the characteristics of climate literacy changes among junior high school students who have participated in a climate change SSI-STEAM program?

2 Theoretical Background

2.1 *Climate Change Education*

Climate change occurs naturally, but it has become clear that anthropogenic factors also affect it. The temperature of the Earth is estimated to have risen by about 1.0°C compared to the period before industrialization (IPCC, 2014). According to the IPCC (2018), the recent rapid climate change has caused extreme weather conditions which threaten ecosystems and human beings. Experts worldwide say climate change is ongoing and poses a significant threat to our present and future (Sanson et al., 2019). Global response to the climate

crisis continues to be based on predictions that reducing carbon dioxide emissions caused by human activities will mitigate global warming.

People's democratic participation based upon scientific understanding and concerns is essential to cope with climate change. Therefore, science education must be at the center of action for climate change education (Hodson, 2003). Because climate change occurs over an extended period due to the slow though steady accumulation of greenhouse gases in the atmosphere, the students of today will still be stakeholders in this problem when they become adults (Yoon, 2009). As mass media and schools' education curricula now frequently address the issue of climate change, public awareness of climate change is increasing. Although adolescents have a higher understanding of the importance of responding to climate change, all students' social participation in climate change action is essential (Cha & Lee, 2017) if we are to mitigate the climate crisis. Therefore, students' capability to understand, judge, make decisions, and take action on climate change issues should be fostered. Considering the content and direction of climate change education in prior research, climate change education should now address climate change and the perceptions and actions that need to be adopted in order to respond to it.

2.2 *Climate Change and SSI-STEAM Education*

SSIs are controversial social issues related to science. SSI education aims at promoting individual intellectual development in terms of morality, ethics, and an awareness of the interdependence of science and society (Zeidler et al., 2005). SSI topics are unstructured problems with no correct answers, including topics such as climate change, environmental issues, cloning, stem cells, space development, resource depletion, and alternative energy. Scientific problems with social implications continue to arise and evolve (Lee, 2018). In particular, climate change is one of the most representative SSI problems of our time and is one that grows ever more complex. Ga et al. (2019) reported that climate literacy was the topic most correlated with SSI when articles in major science education journals were analyzed for common research topic keywords. Hence we determined that climate literacy would be a useful topic to explore in terms of the SSI perspective and that the concept also needed more investigation regarding how it could be integrated into our education system. Climate change education is essential for discussion of and judgment on climate change. In science education, addressing climate change should involve more than just understanding climate science. Teachers should help students to understand complex issues related to climate change and participate in decision-making and social responses (Zeidler et al., 2019). This educational approach is in line with the purpose of SSI education. In this study, we

suggest an SSI-STEM education approach for a climate change learning experience. The multi-perspective and inter-disciplinary approach required to deal with complicated problems can be achieved by STEM convergence education (Bybee, 2010).

As STEM education began to receive global attention, the concept of STEAM (arts-integrated STEM) education, which emphasized raising citizens with creative and convergent competence, also emerged (Kim et al., 2012). STEAM education sought to expand to cover all disciplines, including science (S), technology (T), engineering (E), and mathematics (M), by adding liberal and fine arts (A) to the existing STEM program. STEAM allows students to develop their ability to engage in critical discussions from various perspectives on humanities, society, and the arts (Colucci-Gray et al., 2019). Prior studies have shown that STEAM education programs improve students' creativity and learning immersion and help foster creative talent (Cho & Lee, 2014; Mun et al., 2017). For STEAM education to occur in the mid- and long-term, the development of STEAM education programs that utilize various STEAM dimensions will need to be actively discussed (Kim & Shim, 2017). Kim et al. (2012) presented three dimensions of convergence as guidelines for developing STEAM education programs: unit of convergence, degree of convergence, and the context of convergence (Figure 1).

STEAM education can be linked to climate change education in that it emphasizes intersection. SSIs generally include complicated convergences across diverse areas and involve striving to both understand problem situations and resolve them. Like other SSIs, climate change problems also require

FIGURE 1 Three elements of convergence (Kim et al., 2012)

an inter-disciplinary approach involving science, politics, and society (Lee, 2012). Convergence aspects are the most important parts of both SS1 and STEAM offering an inter-disciplinary approach to climate change, and that is why we used the framework proposed by Kim et al. (2012). SS1 education based on the STEAM educational approach will help students improve their inter-disciplinary and convergent thinking skills about climate change, encourage creativity, and foster climate literacy (Lee, 2016; Madden et al., 2013).

2.3 *Climate Literacy Definition and Constituent Elements*

Scientific literacy involves learning, informed decision-making, and creative problem-solving based on scientific knowledge, as well as the ability to develop scientific exploration skills and attitudes (Lee, 2014; Bae, 2019). The development of scientific literacy has been presented as a goal of science education worldwide. Recent discussions on scientific literacy have further emphasized its expansion from existing definitions to scientific engagement and action (Sjöström & Eilks, 2018). As scientific literacy has been discussed, its applications related to Earth, ocean, atmosphere, and climate science have been of particular interest (Dupigny-Giux, 2010). Among these, climate literacy has acquired a new emphasis (Milér & Sládek, 2011). The impact of heat waves, floods, and ecological changes due to anthropogenic factors has become severe, and the topic of climate change has now 'arrived' in modern society (Arndt & LaDue, 2008).

Azevedo and Marques (2017) considered climate literacy 'to be a context of application in science literacy' (p. 4). The definition of climate literacy in most previous studies has been constructed based on the statement of USGCRP (2009; Dupigny-Giroux, 2010; Park et al., 2010; Park, 2013; Shwom et al., 2017). This implied some agreement on the basic concept of climate literacy, even if some specific elements differed somewhat according to each study's unique context. Based on our literature review, we have re-conceptualized climate literacy as the ability to make responsible decisions and present solutions to climate change issues based on a scientific understanding of the climate system and climate change. This approach is aligned with other studies.

Climate literacy gathers elements from different perspectives and contexts, including epistemic, emotional, and practical spheres (Park, 2013), and those of perception, attitude, and action (Lee, 2011). Clary and Wandersee (2012) organized their survey of climate change literacy into four sections: interviewees' opinions on climate change knowledge, information sources, content knowledge of climate science, and their opinions on the trustworthiness of climate scientists. Park et al. (2010) suggested three main categories of climate literacy education content: 'the principles of climate change science', 'climate change and human life', and 'adaptation and mitigation of climate change.' We gathered all the elements from the literature and sorted them into common areas. We

aimed to synthesise climate literacy as the ability to make responsible decisions and present solutions to climate change based on a scientific understanding of the climate system and climate change. To develop our survey, three major domains of climate literacy were suggested: knowledge, perception, and action (Beck et al., 2013). In the knowledge domain, there are three sub-domains: causes, impacts, and responses to climate change. In the perception domain, susceptibility, issue recognition, attitudes toward choice, and control point were included. The action domain is divided into two sub-domains: individual and community, national and global. These elements are summarized in Table 1. A climate change education program and a climate literacy questionnaire were developed based on the domains and characteristics of climate literacy.

TABLE 1 Domains and characteristics of climate literacy

Domain	Sub-domain	Characteristics
Knowledge	Causes of climate change	Increase of greenhouse gases, overuse of energy, urbanization, industrialization, and indiscriminate development.
	Impacts of climate change	Environmental impact, social impact, and economic impact.
	Responses to climate change	Individual, community, national and global levels.
Perception	Susceptibility	The sanctity of life, individual empathy perspective.
	Issue recognition	Recognitions of different values on climate change problems and issues.
	Attitudes towards choice	Attitudes towards choosing your position on climate change issues.
	Control point	The individual's perception of personal behavior controlled by oneself or by others.
Action	Individual level	Energy conservation in individuals and families, individuals'/families' efforts to respond to climate change.
	Community, national and global level	Policy investigation and engagement, participation in campaigns and demonstrations, own role within the community, national, and global levels, community, national, and global efforts.

3 Methods

3.1 Research Procedure

The study was planned as an international comparison study between Korea and Australia. However, because of the COVID-19 pandemic, the study was undertaken in Korea only, with the first session between students in the two countries conducted online to explore and discuss climate change issues in Australia and Korea at that time. For example, one topic of the conversation was the huge forest fires in Australia and their impact on human life and animals and plants. The procedures adopted for the study are shown in Figure 2. First, a literature review on climate crisis, SSI-STEAM education approaches, and climate literacy was conducted. Second, a climate literacy questionnaire (CLQ) was developed to identify climate literacy changes among junior high school students before and after the climate crisis SSI-STEAM program.

CLQ: Climate Literacy Questionnaire

FIGURE 2 Research procedure

Through modification and revision, the CLQ was completed, with 48 multiple-choice questions covering the major domains of climate literacy, knowledge, perception, and behavior. During the CLQ development phase, the researchers also developed a climate change SSI-STEAM program with a science teacher participating in the study. The final program consisted of seven class hours at the junior high school level. Third, a pre-implementation survey using the CLQ was conducted. Fourth, the program was implemented at M Junior High School, Seoul, in December 2019. Finally, the data collected were analyzed and a conclusion was drawn. In this process, the convergent design of a mixed-methods study (Creswell, 2014) was used to obtain reliability through an integrated interpretation.

3.2 *Research Participants*

The study was conducted at M Junior High School in the southeastern district of Seoul. This is a district known to house high socio-economic status (SES) families. Students from this area tend to show above-average academic achievement (Kim, 2013), and have a higher rate of enrolment into special purpose high schools, such as high schools for gifted science students or international-level studies (Jeon, 2015). These Korean students showed high levels of interest and involvement during their online session with Australian students, despite having to communicate in English.

At the time of the program implementation, M Junior High School was in the interim period between the end of final exams and the beginning of the winter vacation, so the students generally had lower motivation to take new classes. Because of this, the teacher and researchers tried to choose a class with a higher level of academic interest from among the eighth-grade classes. The class chosen had 31 students. These students were assigned into six groups of five or six students each.

3.3 *Development and Implementation of the Program*

The procedures for developing a climate change SSI-STEAM program were as follows: a literature review, development of an initial program, program review by science education researchers and school science teachers, revision by science education experts and school science teachers, and completion of a finalized program. The program was collaboratively developed by science education researchers and a school science teacher and reviewed and modified five times by science education researchers, school science teachers, and earth science education experts. The climate change education program's primary goals were to foster climate literacy, address the climate change topic using an SSI education approach, and reflect STEAM convergence dimensions (Kim

et al., 2012). The three dimensions of convergence were: unit (A), degree (B), and context (C), and each dimension was divided into three categories. The unit of convergence was divided into concept/skills (A1), problem/phenomenon (A2), and activity (A3; in Korean, 체험활동). However, in this study, the dimension of activity (which means creative experiential activity [in Korean, 창의적 체험활동] during schools' discretionary activity programs or during extra/co-curricular time) was excluded because the program was implemented within the framework of the school's regular science lessons. The degrees of convergence were divided into multi-disciplinary (B1), inter-disciplinary (B2), and extra-disciplinary (B3). Contexts of convergence were divided into personal (C1), societal (C2), and global (C3). The details of the climate change SSI-STEAM program are as shown in Table 2.

TABLE 2 Summary of climate change education SSI-STEAM program

Period	Dimensions of convergence	Theme	Content	Class materials
1–2	A1/B1/C3	Motivation	Video meeting with Australian students: Sharing climate change experience Climate change storytelling: Weather, climate, stability collapse, Greta Thunberg's speech, climate action in Korea	Skype, Greta Thunberg's speech video
3	A1/B2/C3	Climate change and its impacts	Organization of Climate Change Countermeasures Headquarters (CCCH): Prepare presentation by investigating climate change phenomena and its impacts on each region based on satellite data (Region: Korea, Australia, polar regions, China, America, and Africa)	Satellite data, internet (using laptops and smartphones)

TABLE 2 Summary of climate change education SSI-STEAM program (*cont.*)

Period	Dimensions of convergence	Theme	Content	Class materials
4	A1/B1/C1	Causes of climate change	Presenting findings from the CCCH by region Causes of climate change (teacher's explanation: greenhouse gas, jet airflow), climate change response (teacher's explanation)	Video materials
5-7	A2/B3/C2	Responses to climate change	Raising awareness through CO ₂ emission Flash program activity (teacher-led) Making climate change stickers (creating drafts using 4 elements of mark design) Presenting photos of climate change stickers attachment with purpose	Flash program, climate change sticker photographs

Note: Unit of convergence – A1: concept/skills, A2: problem/phenomenon, A3: activity; Degree of convergence – B1: multi-disciplinary, B2: inter-disciplinary, B3: extra-disciplinary; Context of convergence – C1: personal, C2: societal, C3: global

The process of implementing the seven-session program was as follows. In the first session, students in the two countries met via video conferencing, to motivate their interest in climate change issues (Figure 3). Students shared their experiences of climate change in Korea and Australia and realized that it is a global problem. In the second session, climate change storytelling was introduced by the teacher. After explaining the concept of weather and climate, the teacher showed videos of domestic and foreign climate change action programs. At the same time, teachers emphasized the importance of climate change education.

In the third session, the students were divided into six groups. Each group formed a Climate Change Countermeasures Headquarters (CCCH) to investigate the climate change phenomenon and its impact on specific regions of the

FIGURE 3 Video meeting with Australian students at the first session

FIGURE 4 Activity outputs of CCCH (Australia by Group 3 and Korea by Group 4)

Earth. The areas to be explored were Korea, Australia, the polar regions, China, America, and Africa, and each group was asked to choose one of these regions. Two group activity outcomes are shown in Figure 4. The first one generated by Group 3 is on Australia's situation, and the other two figures from Group 4 are about Korea. The results of students' investigations were displayed in the school corridors after the class. The display aimed to increase students' interest in climate change and awareness of its global nature.

In the fourth session, each group presented its findings from the CCCH activities, and the teacher introduced the causes of climate change. The fifth and sixth sessions were held for two consecutive class hours. The class first began with a Flash activity focusing on estimating one's own carbon dioxide emissions aimed at alerting students to climate change issues. Later, the teacher

FIGURE 5 Climate change stickers developed by students

introduced a climate change sticker-making activity to inform people about climate change risks and encourage them to act against them. The teacher guided students on how to provide meaningful messages related to climate change in the design of their stickers. Students attached climate change stickers they had produced wherever they thought appropriate in the seventh session and they took pictures (Figure 5). They also presented their stickers using PowerPoint and explained their meaning and design.

3.4 Climate Literacy Questionnaire (CLQ)

To investigate students’ changes in climate literacy after attending the program, a climate literacy framework was developed. The first version of the CLQ was developed based on the climate literacy framework and related prior studies and questionnaires (Byoen, 2014; Jung & Seo, 2008; Karatekin & Uysal, 2018; Kwon & Moon, 2009; Park & Kim, 2020; Ryu, 2011). Forty-eight multiple-choice questions were finally created, with 16 questions per domain, after revising the questions while taking into consideration the level and context of Korean junior high school students. The three major domains and sub-domains of the CLQ are shown in Table 3. The knowledge domain of the CLQ comprised the causes and impacts of climate change, and the items in the domain were developed as true/false options. The perception domain was constructed with items on susceptibility, issue recognition, attitudes toward choice, and control point, while the action domain consisted of items referring to the individual and social levels. The perception domain and the action domain were developed using the Likert scale. Additionally, as a primary survey, 12 background questions were distributed to students to investigate their prior knowledge and background information (Choi, 2021).

TABLE 3 The structure of the CLQ

Domain	Sub-domain	Number of items	Question number	Question Type
Knowledge	Causes	8	1–8	True/false
	Impacts	8	9–16	
Perception	Susceptibility	3	2, 7, 15	Likert scale
	Issue recognition	7	3–5, 11–14	
	Attitudes toward choice	3	1, 8, 16	
	Control point	3	6, 9, 10	
Action	Individual	9	1, 3–6, 10, 11, 13, 14	
	Social	7	2, 7–9, 12, 15, 16	

Background questions (12) requiring written responses were provided with the CLQ.

Total 48 CLQ questions and 12 Background questions

The content validity index (CVI) of the CLQ was estimated by 13 graduate students in science education. The CVI value of the CLQ items ranged from .846 to 1.000, and all items showed above the appropriate level (.75). The reliability of the CLQ was estimated using Cronbach's α . The range of Cronbach's α was above .7 in all domains: knowledge domain .737 (pre-) and .741 (post-), perception domain .761 (pre-) and .879 (post-), and action domain .839 (pre-) and .797 (post-), as shown in Table 4.

TABLE 4 The reliability of the CLQ

Domain	Cronbach's α	
	Pre	Post
Knowledge	.737	.741
Perception	.761	.879
Action	.839	.797

3.5 *Data Collection*

3.5.1 Pre- and Post-Survey

Data were collected through the CLQ developed in this study, measuring the climate literacy of students before and after implementation of the climate change SSI-STEAM program. The pre-survey was conducted before the first class and took 15–20 minutes. The post-survey was conducted after the last class, also taking 15–20 minutes. All 31 student participants completed the questionnaire. Background questions were also used to gauge the students' understanding of climate change in the pre- and post-surveys.

3.5.2 Interviews and Students' Productions during Activities

After the climate change SSI-STEAM program, 18 students who actively participated in the program and showed changes in their climate literacy afterwards were selected for interview. Each interview took about 20 minutes for each student. The interview consisted of seven questions aimed at identifying the characteristics of the changes in the students' climate literacy. The interview data were also used to check the authenticity and reliability of the analysis based on other data sources. All interview data were audiotape-recorded, transcribed, and analyzed. Artifacts produced during the students' activities, including presentation materials such as the climate crisis stickers and other items produced during activities such as the CCCH, were also collected.

3.6 *Data Analysis*

3.6.1 Analysis of CLQ Data

We used Excel to analyze the results of the CLQ, with students' responses coded into numbers. For the knowledge domain of the CLQ, if the answer was correct, 1 point was given. The perception and the action domains of the CLQ offered 1 to 5 points, based on a Likert scale. To score negative statements in the perception domain, (for example, 'the risks of climate change are greatly overstated'), the Likert scale was reversed to ensure the validity of the analysis. As a final step, a paired sample t-test was executed to derive statistical results such as the mean value, standard deviation, and significance, using SPSS (version 26).

3.6.2 Analysis of Interview Data

All interviews were recorded and transcribed, and transcription data were analyzed in three coding phases. In the first phase, the interview data were divided into topic units to identify climate change content. In the second phase, codes were assigned according to the climate literacy domains. In the third phase, we categorized the characteristics of students' climate literacy changes (Table 5). The subsequent process of analysis involved online conferencing five times

TABLE 5 An example of interview data analysis using three coding phases – Jumi’s interview

Coding phase	Coding	Pre- and post-interview examples
1st coding: topic unit	Personal empathy	Pre-test interview data: It used to be nothing. I didn’t think about it.
2nd coding: climate literacy domain	Perception – Susceptibility	Post-test interview data: I feel guilty if I keep the water running for a long time in the shower, and
3rd coding: Characteristics of students’ climate literacy changes	Relevance – recognition	I think I did something wrong, and I think I’ve been thinking a little bit more about each aspect of my life since I took the class.

with 13 graduate students in science education. During the conferencing, the focus was on discussing, reviewing, modifying, and supplementing the analysis, to ensure the reliability and validity of the coding.

3.6.3 Analysis of Students’ Productions and Basic Survey Data
We collected students’ productions during activities, such as presentation materials and climate change stickers. We conducted a primary survey on prior knowledge and background on climate change when conducting the pre-CLQ survey. Since these data were used to supplement the findings and check the results from other sources for triangulation, only primary and secondary coding was carried out (Table 6).

4 Results

4.1 *The Impacts of an SSI-STEAM Program on Climate Literacy*
In this section, we share findings from questionnaire responses and interviews with student participants to describe the impact of participation in the SSI-STEAM program on students’ climate literacy in terms of knowledge and

TABLE 6 An example of two-step coding for an activity production – Ryan's climate change sticker

Picture and content of sticker	First coding	Second coding
Waste of electricity	Knowledge (Causes of climate change)
Purpose is to induce electricity conservation practices.	Need to save electricity	Knowledge (Response to climate change)
Turning on the screen wastes electricity. Turning off the power reduces useless waste of electricity.	Need to induce electrical saving practice	Perception (Attitudes toward choice)

perceptions about climate change and on action outcomes as described in interviews and through analysis of students' activity production.

4.1.1 Pre- and Post-Test Comparisons of Climate Literacy

A paired sample t-test was executed to understand the impacts of the program on climate literacy. The results showed significant increases in the domains of perception ($p = .038$) and action ($p = .000$), but no statistically significant change was found in the knowledge domain (Table 7).

Among the 31 participants, 14 students had taken classes on climate change, while 17 had never taken courses on climate change. Therefore, the students were classified into two groups based on their previous climate change learning experience, to understand the influence of prior learning on this study. After the program, the differences between the pre- and post-program CLQ results of the two groups were compared to identify the climate literacy changes in the students (Table 8).

The differences between post- and pre-test scores for students who had taken climate change classes were -0.035 in the knowledge domain, 0.004 in the perception domain, and 0.214 in the behaviour domain. Students who had taken climate change lessons showed smaller changes in their scores of climate literacy than students who had not taken classes, and the results of

TABLE 7 Pre- and post-tests comparison in CLQ (N = 31)

Domain	CLQ	N	M	S.D.	<i>t-value</i>	<i>p-value</i>
Knowledge	Pre	31	.85	.158	1.55	.132
	Post	31	.89	.137		
Perception	Pre	31	3.89	.426	2.17	.038*
	Post	31	4.03	.516		
Action	Pre	31	2.85	.610	4.45	.000**
	Post	31	3.22	.549		

p* < .05, *p* < .01
M: Mean, S.D.: Standard Deviation

TABLE 8 Changes in CLQ based on previous experience in climate change learning

Domain	Previous experience	Post-Test (M2) ± SD	Pre-Test (M1) ± SD	(M2–M1) ± SD	<i>t-value</i>
Knowledge	Yes (14)	0.880 ± 0.169	0.915 ± 0.102	−.035 ± 0.124	0.05*
	No (17)	0.901 ± 0.108	0.798 ± 0.178	.103 ± 0.132	
Perception	Yes (14)	4.022 ± 0.526	4.018 ± 0.445	.004 ± 0.252	2.00
	No (17)	4.044 ± 0.524	3.790 ± 0.394	.254 ± 0.406	
Action	Yes (14)	3.160 ± 0.617	2.946 ± 2.946	.214 ± 0.269	0.73
	No (17)	3.268 ± 0.501	2.776 ± 2.776	.492 ± 0.547	

**p* < 0.05
M1: mean value of pre-survey, M2: mean value of post-survey, SD: Standard Deviation

changes in the knowledge domain showed negative mean score (−.035 ± 0.124) even though they had participated in the SSI-STEAM program. However, the pre- and post-test score differences were not statistically significant. There were statistically significant group differences between the groups’ (with climate change class experience – the ‘yes’ group and without climate change

lesson experience – the ‘no’ group) climate literacy score charges in the knowledge domain (Yes: 0.035 ± 0.124 ; No: 0.103 ± 0.132 ; $t = 0.05$, $p < 0.006$). The group of students who had not had lessons in school on the topic of climate change before the climate change classes showed more score changes than the group of students who had had such learning experiences. In other domains (perception and action), students with no climate change lesson experiences also showed bigger differences between pre- and post-test scores, but these groups’ differences were not statistically significant.

The findings, given in Table 8, showed that most students who participated in the climate change SSI-STEAM program generally showed higher climate literacy scores across domains. In particular, we can see that the program had a positive effect on those who had never taken classes on climate change. The results of each domain of CLQ are as follows.

4.1.2 The Impacts of the Program on the Knowledge Domain

The CLQ results showed that after the climate change SSI-STEAM program, students’ mean scores in climate literacy in the knowledge domain increased from .85 to .89 (see Table 7). However, the change was not statistically significant because participants’ literacy in the knowledge domain was high from the beginning. Only Question 4 showed a substantial increase in the knowledge domain (Figure 6). This item elicits knowledge about the causes of climate change, using the statement, ‘The cause of climate change is an increase in carbon dioxide in the air.’ About three-quarters of the participants (77.4%, 24 students) answered Question 4 correctly before the program. After the program, the proportion of correct responses rose to 96.8% (30 students).

FIGURE 6 Comparison of average scores for items in the knowledge domain between pre- and post-survey

FIGURE 7 Comparison of average scores for items in the perception domain between pre- and post-survey

There are three possible reasons for these results: First, the third to fifth lessons in the program dealt with the correlation between carbon dioxide growth and rapid climate change. Second, global and regional carbon dioxide growth graphs were provided during the activities of the CCCH. Third, during the class, the teacher steadily talked about increasing carbon dioxide.

4.1.3 The Impacts of the Program on the Perception Domain

Participants' perceptions of climate change changed substantially after attending the program. The average score in this domain changed from 3.89 (pre-) to 4.03 (post-), a difference that is statistically significant at the .05 level ($p = .038$). Among 16 items, five showed positive, meaningful changes. All three items, 2, 7, and 15, categorized under the susceptibility sub-domain, showed positive changes. On the contrary, little difference was found in attitude-related items. Partial changes were revealed in items in the control point sub-domain. One negative change was found in Item 13, 'issue recognition' (Figure 7). The statement in Question 13 was, 'I think the Korean government is coping well with climate change.' The negative change in this item was due to the teacher's critical stance on the Korean government's responses to climate change. Evidence of significant changes to students' climate change literacy in their responses to all seven questions could be closely related to the participants' experience in the program.

4.1.4 The Impacts of the Program on the Action Domain

Participants' responses to items on climate change action changed substantially after attending the program (Figure 8). The average score in this domain changed from 2.85 (pre-) to 3.22 (post-), the difference being statistically

FIGURE 8 Comparison of average scores for items in the action domain between the pre- and post-surveys

FIGURE 9 Characteristics of climate literacy change

significant at the .01 level ($p = .00$). Among 16 items, five showed positive and meaningful changes. Among the five items showing a considerable difference, three were in the individual level sub-domain and two were in the community, national, and global level sub-domains. However, no specific patterns associated with the sub-domains were found.

4.2 The Characteristics of Climate Literacy Change

The characteristics of climate literacy change patterns among participants were analyzed based on interview data analysis and were then classified into four categories: ideas become more concrete than before, expansion of the scope of thinking, positive responsibility, and relevance recognition. Except for the first category, more concrete ideas, each of the three categories was also divided into two sub-categories (Figure 9). The characteristics of climate

literacy change among participants after the climate change SSI-STEAM program are described by category.

4.2.1 Ideas Become More Concrete

After participation in the program, participants' previously abstract or general concepts became more concrete, or 'embodied'. Sam said he thought abstractly about the impact of climate change before attending the program. However, he learned about the effects of climate change during the program, including information about rising sea levels and abnormal weather conditions. His earlier ambiguous ideas became more concrete after attending the program.

- Researcher: What did you learn through the program?
 Sam: Before the program, climate change was ambiguous in my mind. But after the program, [my understanding] about the sea level going up, and various abnormal weather conditions occurring, I thought it was more complex than I thought before.

Jumi said she did not exactly know about climate change until she took the program. She responded to the post-class background questions using the specific terms 'ecosystem', 'desertification', 'drought', 'ecosystem', 'desertification', 'drought,' and 'typhoon' when discussing the impacts of climate change.

- Researcher: You wrote in the pre-survey before the program, "Many people die and money is lost because of climate change." But after the program, you wrote "ecosystem, desertification, drought, and typhoon" very specifically. Did you learn more specific information from this class?
 Jumi: Yes. I knew it roughly before, but not exactly. I didn't know what was going on in detail, but I learned more about those things after the program

Before the climate change SSI-STEAM program, some students already had knowledge about climate change. An analysis of students' climate literacy changes after the program found that their prior knowledge was further subdivided and embodied.

For example, Hyeji had prior knowledge of climate change through her experience in science club activities before participating in the program.

However, she was aware of the impacts of climate change only in terms of rising temperatures. After doing the climate change lessons in this program, the concept of temperature rise was now properly embodied for her in the risks it could produce in real life.

- Researcher: Is there anything you remember, especially from the activities of the CCCH?
- Hyeji: I thought climate change would only raise the temperature, but I also learned that the sea level would rise. It was interesting to know that not only does it get hot, but also, the sea level goes up. And the temperature around the world is only going up by 1°C, and that's serious enough to make it a big problem ... I've never thought that a temperature rise of 1°C could cause our death.

The students' initial ideas concerning the impacts of climate change had become more concrete, or embodied. This seems to have been the result of researching and announcing the global and regional environmental, social, and economic effects of climate change during the CCCH activities.

4.2.2 Expansion of the Scope of the Perceived Subject

After participating in the program, participants showed an expanded awareness of which actors should work to cope with climate change. Before attending the program, Kitae responded that to mitigate climate change, 'the people' are essential. However, after the program, he answered that, 'the government is also essential as well as the people'. This showed that he had expanded his scope for reflecting on the subject of climate change.

- Researcher: Before the program, you wrote in the pre-survey that 'the people' were the most important in responding to climate change. But after the program, you said both 'the government and the people' were important and wrote that the "government should strengthen policy and people should make efforts." Why did you change your mind?
- Kitae: There are some areas that the people are not able to work on. I think the government needs support because certain areas can't be fixed no matter how hard they [the people] try.

Emma also broadened her scope from domestic government to international collaboration. Before attending the program, she answered that ‘the government and the people’ were important in coping with climate change. However, after the program, her response was expanded to ‘the international community, the government, and the people.’

- Researcher: Before the program, you wrote that the “government and the people” are important in coping with climate change. But after the program, you changed to “the international community, the government, and the people.” are important. Why was it changed?
- Emma: Rather than just the government’s efforts, I think an overall international effort will have a greater impact on preventing climate change. I think that’s what I felt on the whole while taking the class.

These results may have arisen from the video conferencing with Australian students in the program, and from students’ experiences during CCCH activities while investigating the continents on which climate change had the most significant impact.

4.2.3 Expansion of the Scope of Action

After the program, some participants also revealed their expanded notions of the scope of climate change action needed from the individual to the community, national, and global levels. For example, Hyeji only mentioned individual-level actions to address climate change before the program. However, after attending the program, she was willing to participate in social actions such as protests because of the seriousness of climate change.

- Researcher: Before the program, you wrote that “People should reduce disposable products, unplug, and use tumblers” to solve climate change. But after class, you wrote that “People should mitigate the seriousness of climate change around them.” Is there a reason why you changed your mind in this way?
- Hyeji: To be honest, I didn’t know much before the program. I wasn’t sure what I was doing. But after attending the program, it became clear what I should do, so I thought, “I should let others know this.”

- Researcher: Then, if there's a demonstration, would you like to participate?
- Hyeji: It's too much for me to tackle alone, but if my friends ask me to go with them, I'll definitely go.

This change seems to be the result of the program, which deals with activities not only at the individual level but also at the community, national and, global levels of climate change response. Through designing, making, and posting climate change stickers, students seemed to experience the need for, and means of, social action about climate change issues as well as increase their willingness to take individual action.

4.2.4 Positive Responsibility

After attending the program, students became positive about dealing with the climate change problem. For instance, before the program, Yuri thought the climate change problem would be impossible to solve, but after attending the program, she felt that it would be possible to solve it.

- Researcher: When asked if you could solve climate change before the program, you wrote "No," but after the program, you wrote "Yes. I think it can be solved if people save energy." Why did you change your mind?
- Yuri: Previously, I thought people couldn't find a solution, but after the program, I thought it would be possible if many people acted.

Before joining the program, Jieun also believed that climate change had already progressed and could not be solved. However, after attending the program, she said that climate change could be solved. She seems to have changed her mind because, during the program, she heard experts' opinions that climate change is still in a recoverable range.

- Researcher: Before the program, when asked about solving climate change, you wrote, "No. We can't solve climate change because it's already in progress." After class, you wrote, "Yes. I think there is room to solve climate change." Is there a reason for this change?

Jieun: The teacher said that the average temperature of the Earth has risen by 1.0°C , but from 2.0°C , it can no longer go back and recover. That means there's still room for recovery now: experts' opinions are that it might be possible to recover.

4.2.5 Subjectivity Due to Responsibility

After attending this program, participants' sense of responsibility for mitigating climate change increased, which led to their own initiatives for climate change. Jieun said that after watching Greta Thunberg's demonstration video and the Korean students' school absence demonstration video, she thought, 'I should do something.' She did not take any action for climate change before the program, but now she would be likely to feel guilty after participating in the program if she did not do anything.

She also expressed her willingness to work toward responsible actions because she thought that she did not deserve to argue later if she does nothing now.

Jieun: I should do something. I think we should post something online or do something. I feel guilty when I don't do anything.

Researcher: Why do you think that?

Jieun: Greta Thunberg is the same age as me, but she thinks and acts on her own. I don't do that yet, but she talks about our future and goes out to protest. But if I just take a shower for a long time, eat a lot of meat, and go to school as usual, I won't deserve to argue with people about any problems in the future.

4.3 *Relevance Recognition*

4.3.1 Recognizing the Relationship between Climate Change and Oneself

After attending this program, students learned that the climate change problem was related to them: They affected climate change and climate change affected them. Clara had previously thought that climate change was not related to her. However, after attending this program, she said that she was aware that climate change significantly affected her.

Researcher: How were your classes?

- Clara: I was touched by things that I had previously been indifferent to. I realized that this is what happens due to climate change.
- Researcher: How have you changed since you took the program?
- Clara: When I heard about climate change in the past, I thought it had nothing to do with me. But when I took the classes, I realized that climate change has a big impact on me.

Before attending this program, Hyeji said that she did not think there was anything she could do to cope with climate change and that she did not believe she would have much impact on climate change. But after attending the program, she said she had learned that even one piece of trash she threw away could have a significant effect.

- Researcher: What did you think about climate change after taking the program?
- Hyeji: Climate change used to be so ... I thought, "What will happen to the world if I throw this away?" But all the things I threw away are going to a plastic island or somewhere. I thought that "I have a tremendous impact. I should try to cope with climate change."

4.3.2 Action Change Due to Empathy

After participating in the program, students said they felt guilty and experienced remorse when they did something that worsened climate change. They also responded that the climate change issue was shocking. In other words, students were aware of their connection to climate change, which led to changes in their actions.

Jumi said that before attending this program, she did not care about the behavior that caused climate change. However, she said that after attending the program, she felt guilty if she ran tap water for a long time or wasted resources. After attending the program, she also made an effort to save paper.

- Researcher: How did you feel to find out that you have a lot of influence on climate change?
- Jumi: I feel guilty if I run tap water for a long time for a shower and if I waste resources. I didn't think much about it before, but these days, I think I did something wrong.

- Researcher: Then, did you actually change anything after taking the program?
- Jumi: Usually, I don't save my notebooks, write in large letters, but these days, I write small letters and fill them up.

Ryan says he had not paid much attention to saving electricity. However, after participating in the program, whenever he came out of a room, reminded of the learning from the program, he felt remorse and turned off the lights. Throughout the program, the teacher tried to convey the message that climate change is related to us and that everyone should solve it together, starting from the individual level.

- Researcher: How do you think this class affected your behavior?
- Ryan: First of all, I've saved a lot of electricity.
- Researcher: After the program? How?
- Ryan: I usually don't turn off the lights in my room because I'm too lazy, but on my way to the door, I thought of the lesson I had, so I turned the light off because I felt guilty.

The results of the analysis can be summarised as follows. In the knowledge domain, no significant change was found in the quantitative data. However, the interview data showed that students' knowledge of climate change developed more precisely, and their perspectives expanded from individual level to the social and even the global levels. In the perception domain, students considered climate change issues relevant to themselves and clearly revealed their position on climate change issues. They also indicated that they had a more proactive view of solving the climate change problem. In the action domain, there was a significant increase in student behavior at the individual level in response to climate change issues. This result was consistent with those of quantitative data. However, most of the students' behavior was still at the individual level. The program needs to be revised to make meaningful changes in participants' behavior.

5 Conclusion and Discussion

In this study, we developed a climate change SSI-STEAM education program to cultivate climate literacy and implemented the program at a junior high school in Seoul, Korea. We also developed a climate literacy questionnaire (CLQ) to understand the impacts of the program on students' climate literacy. Before

and after participating in the program, students were asked to conduct CLQ surveys, and after the program, some students were interviewed in-depth to collect qualitative data. Based on quantitative and qualitative data, we analyzed the effects of our program on students' climate literacy and the characteristics of the resulting changes in students' climate literacy. From the results, the following conclusions were drawn.

First, the climate change SSI-STEAM program developed and applied in this study could affect junior high school students' climate literacy. According to the quantitative data collected in the CLQ survey, the program had a positive effect on the perception and action domains of climate literacy. Although no significant improvement was shown in the knowledge domain of climate literacy, the results of qualitative analysis, including interview data, showed a positive impact on the knowledge domain. Therefore, we concluded that the SSI-STEAM climate change education program positively affects students' climate literacy and leads to a change in students' climate literacy, based on our analysis of both quantitative and qualitative data.

Second, there were four characteristics of climate literacy change for students: ideas became more concrete, the scope of their thinking expanded, their positive responsibility was enhanced, and their capacity for relevance recognition increased. After participating in the program, students' general ideas and prior knowledge became more concrete, or embodied. The expansion of the scope of thinking was divided into two categories: expansion of the scope of the perceived subject and expansion of the scope of action. Therefore, after attending the program, students were able to realize that the scope of climate change responses should be broadened, not just among the people but also in terms of action by the government and the international community. They also expanded their perception of the scope for action from the individual level to the social level, including the community, national, and global levels. Positive responsibility can also be divided into two categories: a positive mind and subjectivity due to personal responsibility. After participating in the program, students became more optimistic that climate change could be solved and, at the same time, had their own views based on their responsibility for the climate change problem. Relevance recognition was divided into recognizing the relationship between climate change and oneself, and a change in action due to increased empathy. After participating in the program, students realized the close relationship between climate change and themselves, leading them to change.

Finally, we considered the characteristics of the changes in students' climate literacy in terms of the purpose of climate change education. The purpose of climate education pursued in this study was to have the ability to judge

and make decisions on climate change issues based on a level of knowledge and perception of climate change issues that can eventually lead to action. This purpose aligns with that of global citizenship education, which includes all three domains of learning: cognitive, socio-emotional, and behavioral (UNESCO, 2014). Before participating in the program, most students were vaguely aware of climate change but did not know about the causes or effects of climate change. However, after participating in the program, many students had more specific knowledge about climate change, realized the seriousness of climate change, and felt a responsibility to solve it. Therefore, we concluded that the knowledge, perception, and action domains of climate literacy are interrelated step by step and that the program comprehensively affects students across all three domains.

The findings of this study were related to the characteristics of the program, participants, and the context. The program was designed to build climate literacy within the domains of knowledge, perception, and action. Therefore, it included the science of, impacts of, and action against climate change. The program also featured various student-centered activities, including video conferencing with Australian students, investigating climate change at places all over the Earth (CCCH), and sticker production. The program's content and methods have the potential to provide students with opportunities to understand the science and impacts of climate change and to take action to mitigate climate change.

The school where the students participated in this study is located in a wealthy area in Seoul. Students in this district generally have higher academic abilities and also higher levels of English communication. At the beginning of the program, because of their good English communication skills they could experience and enjoy video conferencing with Australian students about climate change without the support of English-Korean translators. The students' backgrounds may have contributed to their motivation to participate in the program and to the positive changes in their climate literacy.

The context may also have played some role in these changes in climate literacy. The time of program implementation was near the end of the academic year. Students usually lose attention and motivation to study at this point in the year. Fortunately, however, students' participation in the program, both in terms of engagement and motivation, was satisfactory. One other difficulty was securing enough class hours for the program. However, only seven class hours were available. The teacher had to adjust the schedule and activities in the action domain, so activities in the action domain were reduced to the individual level, excluding the social action segment. As a result, only the students' individual-level actions were identified after the program. However, students did express their intentions of action at the community, national, and global

levels. Therefore, the contribution of contextual factors to climate literacy needs further investigation. In addition, a significant change had also occurred in the context of the study.

There have been few studies on climate literacy, whether in Korea or elsewhere. More studies need to be conducted, and the concept of climate literacy, including definitions, domains, and characteristics, needs to be elaborated. Four characteristics of climate literacy, including ideas become more concrete, expansion of the scope of thinking, positive responsibility, and relevance recognition are identified in this study. Further studies conducted in different contexts with different programs and participants are needed to understand the characteristics of climate literacy.

Climate change education is urgent considering the impacts of climate change on human wellbeing and the Earth's environment. It should be made an essential part of formal education as soon as possible. However, the existing education system, including national curricula, subject matter, teacher preparation systems, and national assessments, makes this difficult. We now urgently need to develop a social consensus in favor of introducing climate change education into both formal and informal education systems.

Abbreviations

CCCH	Climate Crisis Countermeasures Headquarters
CLQ	Climate Literacy Questionnaire
CVI	Content Validity Index
IPCC	Intergovernmental Panel on Climate Change
SSI	Socioscientific Issues
STEAM	Science, Technology, Engineering, Art, Mathematics

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Ethical Consideration

Approval to conduct this study was granted by the Seoul National University Ethics Review Board. 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 this study are all pseudonyms. Any photos and images appearing in this paper were provided with permission of the participant.

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