The Development of a STEAM Program about Global Energy with a Focus on Democratic Citizenship

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Received: 20 October 2021 | Revised: 28 April 2022 | Accepted: 10 May 2022

Abstract

This study explored democratic citizenship (DC) for students by developing a DC framework (DCF) with eight components. We employed the DCF to examine what and how much DC was included in Korean science textbooks and lab books focused on the topic of energy for Grades K–12. We found different DC components were included at different grade levels and some components were not present at all. To help address
the uneven distribution of these components, we developed four DC inclusive science, technology, engineering, arts, and mathematics (STEAM) books related to the topic of energy. These books were designed with the DCF to foster rich DC learning experiences in school science. We engaged 13 teachers as consultants in a validation process when developing the DC inclusive STEAM books. This study describes the development and implementation of the DCF for preparing supplemental science curriculum materials that can improve students’ appreciation for DC.

초록

이 연구는 8개의 요소로 구성된 민주시민소양틀을 개발하여 학생들 소양향상에 사용하고자 탐색하는 것이다. 연구자들은 이를 이용하여 우선 초중등과정에서 사용되는 과학교재 및 관련실험책에서 에너지이슈 관련 주제를 선정하고 민주시민 소양의 요소가 무엇이 포함되어 있고 또한 얼마나 포함되어 있는지를 조사하였다. 초등, 중학교, 및 고등학교 과학 및 실험교재에서는 각각 다른 요소가 포함되어 있으며 어떤 요소는 포함되어 있지 않을을 알게 되었다. 상대적으로 낮게 포함되거나 나타나지 않는 민주시민소양 요소를 학습할 수 있도록 에너지 주제로 풍부한 민주시민소양의 함양목적으로 STEAM 프로그램을 개발하였다. 13명의 교사들이 내용의 타당성을 검증하였고 학생들의 민주시민소양의 함양을 목적으로 하는 과학과교육과정의 보충자료로 사용하는데 이 연구에서 개발된 민주시민소양틀의 활용은 의미가 있다고 할 수 있었다.

Keywords

democratic citizenship – STEAM – energy – science education

1 Introduction

Education is essential for developing and maintaining a sustainable society based on democratic culture. This education gives members of society the will to resolve various conflicts in our society peacefully, recognizes the decisions of the majority and the rights of minorities to respect diversity, and fosters attitudes and behaviors that do not forgo interest in the physical environment. However, rapid social changes, the resulting decline in trust among members, and the resulting social tensions and conflicts are hindering social integration and sustainable development. In particular, in the education community, experts have pointed out that the current entrance examination and
knowledge-oriented education in countries, like Korea, has limitations for cultivating the community competencies that democratic citizens should have (Kang et al., 2011; Sim, 2017). From this, it can be said that it is crucial to teach democratic citizenship (DC) education. Among the most interesting questions about DC education might be the curriculum question. What outcomes are expected from students during their time at school, what should students learn, and how can teachers equip students with competencies of DC are all important to consider. In the context of science education, researchers and curriculum designers are also concerned about what DC competencies can be taught in science. Parker (2008) argued that democratic citizenship education is deeply contextual, particular to time, place, and circumstance, and it goes to the main purpose of schooling. Thus, it is critical to know what DC is and in what context it can be learned, especially in the context of science learning.

DC includes knowledge of fundamental human and citizen rights, and their impact on everyday life; creative thinking evidenced by use, assessment, and permanent improvement of their own strategies for solving problems; skills of critical judgment and various argumentation techniques; proper understanding of the sense of belonging to different types of communities; and a sense that is acquired through participation in the social life of the classroom, school and local community (Albulescu & Albulescu, 2015). To address these needs in science education, DC emphasizes the need for democratic citizens to be able to exercise their decision-making power through reflective thinking about the problems that may arise in our society in the future. Science educators need to know that future social problems are deeply related to science and technology and we may need to call upon the necessary competencies to carry out problem-solving processes based on scientific knowledge and scientific thinking (Choi et al., 2011; Park, 2016).

In recent years, there has been noticeable changes in science curriculums related to DC. In Korea, for example, there are five objectives written to meet the vision of scientific literacy in science curriculums from elementary to secondary levels (Korean Ministry of Education [MOE], 2015). The 4th objective describes the importance of interrelationships among science, technology, and society (STS), for building knowledge as democratic citizens. Students now take integrated science in year 10, and they can choose to study physics, chemistry, biology and earth science I and II in years 11 and 12. For these courses, students are learning science knowledge and inquiry methods through situations related to daily life with a goal of cultivating scientific literacy and understanding the interrelationship between science and society that will enable students to grow into desirable democratic citizens (MOE, 2015). Science is explicitly defined as a subject seeking to promote literacy of democratic citizens on the
basis of scientific knowledge and STS relationship awareness (Joung, 2016). This emphasis in the curriculum makes science researchers and science teachers interested to know how to better equip students with the competencies of DC so that students can solve conflicts and problems in society (Chang, 2020).

1.1 Democratic Citizenship in the Context of the Korean Education System

Since 2010, the Korean Ministry of Education (MOE) has been pushing for the integration of democratic civic education in schools through a plan to revitalize democratic civic education centered on experience and practice (Kang et al., 2011; MOE, 2015). Democratic civic education is regarded as lifelong education or lifelong learning element that encourages reflective exploration and rational decision-making. Rational decision-making and social behavior models are considered the core goal of democratic civic education to teach students to make reasonable decisions and to act according to their decisions. Social problems in our society in the future will be deeply related to science and technology, and so democratic civic capabilities in science must taught so that students are able to exercise decision-making power through reflective thinking about problems that will arise in our future society (Joung, 2016; Lee, S., 2018; Park & Ok, 2019; Rudolph & Horibe, 2015). Demonstrating critical thinking competency as a citizen is pivotal for citizens to feel the value of democracy and collaborate with each other on shared problems in the community (Chang, 2020).

Social problems in the future will be deeply related to science and technology (e.g., climate change, biotechnology, GMOs, and epidemic response) and there is a need for active participation in addressing social problems based on scientific knowledge and scientific thinking skills, and fostering reflective thinking and problem-solving skills. Democratic civic education should include fostering global science (Choi et al., 2011) by focusing on the need for democratic citizens to make decisions through reflective thinking about problems that arise in future society. We also know that future social problems are deeply related to science and technology, so we can extract the capabilities necessary to perform problem-solving processes based on scientific knowledge and scientific thinking (Kolstø, 2008; Millar & Osborne, 1998), which is interpreted as democratic citizenship. The authors researching democratic citizenship has different terms of their own indicating democratic citizenship. For example, democratic civic education has the same meaning of democratic citizenship. The capability and competency of civic education are considered as the same meaning of democratic citizenship.
1.2 Components of Democratic Citizenship

Citizenship can be achieved when people interact with others in their local areas, countries, and the world (Binkley et al., 2012). There are a number of organizations around the world that have independently created frameworks for 21st century skills, which consist of 10 skill groups divided into 4-categories: *ways of thinking, ways of working, tools for working,* and *living in the world*. Among these, citizenship is included in the ‘living in the world’ category and is described by three areas: *knowledge, skills, and attitudes/values/ethics*.

*Knowledge* refers to civil rights, roles, and responsibilities of institutions relevant to policy-making concepts such as democracy, citizenship, and the international declarations expressing them. *Skills* refers to participation in community/neighborhood activities, as well as, decision-making at national and international levels, and the ability to display solidarity by showing an interest in and helping to solve problems affecting the local or wider community. *Attitude/values/ethics* is about the sense of belonging to one’s locality, country, and the world, willingness to participate in democratic decision-making at all levels, disposition to volunteer and to participate in civic activities, readiness to respect the values and privacy of others, acceptance of the concept of human rights and equality, appreciation and understanding of difference between the value systems of different religious or ethnic groups, and the critical reception of information from mass media. Students need to be taught and assessed on these skills needed in the 21st century (Emdin, 2011; Millar et al., 1998, Lee. S., 2018).

The capacity of democratic citizens is important for the global science as people need to be able to develop decision-making power through reflective thinking (Berland et al., 2016; Choi et al., 2011; Lee et al., 2013). In other words, through communication and cooperation, citizens will be able to think systematically, develop information processing skills, experience empathy, and feel a sense of social responsibility. Also, it includes the capacity of understanding the relationship among STS and of demonstrating self-directed decision-making. Mun et al. (2012) illustrated that developing decision-making ability is a key goal of DC education. Therefore, rational decision-making ability is the most important quality required of citizens in a democracy. It was also said that reflective thinking should include components such as scientific inquiry, problem-solving, and decision-making as they utilize higher thinking ability to find and evaluate problems. Therefore, it has been argued that students should learn to analyze social problems and the related data, not simply memorize or inject cultural heritage, and to think how to solve problems. Accordingly, it is said that students should develop a thinking process and ability to reasonably
solve problems through a thinking process that consists of experience in social problems, systematization of problems, hypothesis setting, exploration and verification, and generalization (Baram-Tsabari & Osborne, 2015). This process is possible through DC education.

1.3 **Democratic Citizenship Education**

How can we promote students’ citizenship during their childhood, especially citizenship related to science? The free semester system and free school year system conducted in Korea offers a good opportunity to strengthen democratic civic education (Choi et al., 2011; Garlick & Levine, 2017; Mun et al., 2012). The free semester system has been run since 2016 in the middle school years. Students in middle schools spend one out of 6 semesters participating in classes that use reading discussions, role playing, career experiences, and project-based learning to explore various topics and careers instead of taking examinations. The initial free semester program has now been extended to a two-semester (free year) program. The use of socio-scientific issues (SSI) education is viewed as a critical factor for educating students as citizens (Lee, 2018; Kahn & Zeidler, 2016; Roth & Désautels, 2004; Solomon & Aikenhead, 1994). Lee, H (2018) argued that SSI education emphasizes social responsibility, practice, and participation beyond individual rational decision-making. In particular, the European Science Education Research Association (ESERA) conference held in Dublin, Ireland, in 2017 introduced the results of the PARRISE project, which universities, belonging to the European Union, have been carrying out for years to foster students’ social responsibility based on SSI education. This project introduced the concept of responsible research and innovation at elementary and secondary levels, and students have the opportunity to participate in and discuss SSI facing society, thereby helping them grow into democratic citizens with authentic scientific knowledge. Additionally, there has been research about what influences middle school students’ attitudes about environmental issues and the experience of making decisions while they were taking science, technology and society (STS) programs made it more effective to feel the responsibility of solving community problems (Cho & Chung, 1995).

We face global issues that must be solved for the next generation. For example, climate change is a serious and well-known issue by students and citizen (Choi et al., 2011; Levinson, 2010; Sengul, 2019; Zeidler et al., 2019) and it is clear that all citizens around the world should recognize that climate change is no longer an issue to be addressed but a challenge to be solved through action. Alternative renewable energy is drawing attention as a solution to climate change (Binkley et al., 2010; Mun et al., 2012; Kolstø, 2008). Understanding
what kinds of renewable and alternative energy are appropriate in Korea’s case can offer citizens’ and students’ opportunities for experiencing DC for citizen science. Many countries around the world are making efforts to solve this problem, and one of their solutions is to develop alternative renewable energies. At this point, it is critical for citizens as well as students to be educated to know what kinds of alternative renewable energies are appropriate in their own country through DC education since it is very easy for them to be exposed to school science learning. Therefore, we explored first how much students have already learned or are exposed to alternative renewable energy issues during their schooling through science curriculum. In order to revitalize DC education, it is essential to first recognize how DC education is being conducted at schools and to figure out the students’ level of competency of DC (Kang et al., 2011).

2 The Purpose of Research

What is the difference between citizenship education and DC education? The Korea MOE is pursuing democratic citizens (Constitution, 1988) so DC is commonly used in Korea, whereas civic education or citizenship education are more generally used in Western countries, which do not have a difference in their meanings (Kang et al., 2011). We agreed to use DC as it has been addressed as one of the learning objectives in the science curriculum (MOE, 2015). Schooling practices make significant contributions to the citizenship of students, and DC education has been researched in the social studies (Abowitz & Harnish, 2006) but we aim to explore DC education in science education with scientific issues that can foster students’ literacy in DC. It is critical for students to be exposed to learning DC during their school-life by their main learning materials, textbooks in this study. The research questions in this study are:

1. What kinds of DC components are students exposed to in relation to the topic of energy in textbooks/lab books and how frequently are those DC components included?
2. What kind of guidelines are needed to include and promote democratic citizenship in energy topic-focused STEAM books?

The reason we selected the topic of the energy issues of climate change from textbooks is that climate change and its solution are well known to students. Secondly, these research questions can result in setting the direction of DC policy making in science curriculums. The significance of this study is that the results can be used as basic information/data to understand how DC can be
embedded in science textbooks and what/how those components of DC can be included according to the guidelines developed by us. This can be the first step to revitalize DC education.

3 Methodology

This research was conducted in four phases: 1) a review of the literature was conducted to develop a democratic citizenship framework to be used for 2) analyzing textbooks to identify content related to energy issues in climate change. After identifying what energy topics related to climate changes were present in science textbooks at different grade levels; we 3) developed a series of new energy-related books using the STEAM approach to teach renewable energy topics related to nuclear, wind power, thermal, and solar energy; and 4) engage teachers as expert consultants to provide feedback about content of the STEAM books and to consider effectiveness for utilizing these books to promote DC education in the context of school science as part of a validation process for the development of the STEAM books. Each phase is described in more detail below.

3.1 The Development of a Democratic Citizenship Frame

From the literature review, we have summarized the competencies of DC in science education as follows: decision-making power through reflective thinking; skills to deal with social problems deeply related to science and technology; interaction with people in the community/participation in community activities as well as decision-making; interest in and helping to solve problems affecting the local or the wider community; sense of belonging to one’s locality, country, and the world; willingness to participate in democratic decision-making at all levels; disposition to volunteer and to participate in civic activities; the capacity of understanding the relationship of science technology, and society (STS); reflective thinking should include thinking such as scientific inquiry, problem-solving, and decision-making.

Building from the theories and practices summarized from our review, we developed the Democratic Citizenship Framework (DCF) (see Table 1). The DCF has eight components, each with a definition and sub-components. The content validity was constructed by the researchers and with consultations with experts in science education. The main components are drawn from the literature reviews and we focused on what competencies of democratic
citizenship (DC) are essential in science education from their practices and theories. For example, the competencies of decision-making power through reflective thinking and reflective thinking should include thinking such as scientific inquiry, problem-solving, and decision-making would be accounted for by the CT (critical thinking) component.

| Component                                      | Definition                                                                 | Sub-Components              |
|------------------------------------------------|----------------------------------------------------------------------------|-----------------------------|
| Critical thinking (CT)                         | logically explain the given problems and information and judge from various perspectives | logical decision/divergent thinking |
| Communication and collaboration (CC)           | process of reaching a compromise by exchanging opinions with colleagues and others during scientific exploration and problem solving | cooperative learning and discussion |
| Information management (IM)                    | provide a way to collect, evaluate, and analyze the information             | data collection/data analysis/data representation |
| Sympathy (S)                                   | share emotion together and increase our empathy for it                      | emotional empathy and ethics responsibility |
| Social accountability (SA)                     | feel and express social responsibility closely in relation to students’ lives |                             |
| Science, technology, and society (STS)         | explain explicitly the relationship between technological development and social change | STS                          |
| Self-directed plan (SD)                        | plan, execute and evaluate what can be done on a personal level to solve the problem | self-directed planning, implementing, and evaluating |
| Decision-making competency (DM)               | enhance decision-making after various alternatives are presented and discuss to compare them to decide which one is the most appropriate and concrete solution | exploring alternatives/making decisions |
The Analysis of Science Textbooks from K to 12 with the Energy Issues

We used this frame to analyze textbooks with a focus on energy issues (Table 2) to see what kind of DC components were included in the textbooks, how much these were included, and what was missing. The energy topics in this study specifically focused renewable energy in relation to the climate change issue (Kahn & Zeidler, 2016; Solomon & Aikenhead, 1994). SSI is considered the

| Table 2 | Grades 6–12 science curriculum with energy content analyzed in this study |
|---------|--------------------------------------------------------------------------------|
| **Level** | **Science curriculum** |
| Elementary level (Grade 6) | Science/practical lesson subjects (Grade 6 only)  
- Water travel (hydroelectric power)  
- Efficient transport (renewable energy)  
- Agriculture in life (alternative energy for petroleum energy) |
| Middle school level (Grades 7–9) | Technology/science subjects  
- Construction technology (high efficiency energy technology)  
- Understanding proper technology (solar heat cooker)  
- Characteristics and circulation of seawater (electric ocean temperature difference from seawater)  
- Electric energy (renewable, wind, hydroelectric) |
| High school level (Grade 10 integrated science and experiment textbooks) (Grade 11–12 physics/chemistry/biology/earth science Levels I & II) | Integrated science  
- Environmental and energy (Effort for renewable energy housing, thermal hydro photovoltaic power generation, comparison of nuclear/thermal power generation with nuclear/carbon zero cities)  
Exploration experiment  
- Advanced Scientific Exploration (Solar power generation, sustainable eco-friendly energy urban design/device design/renewable energy)  
Physics/Chemistry/Biology/Earth Sciences I & II  
- Mechanical energy, energy transformation, internal energy, energy conservation, mass energy, energy status, heat and energy  
- Ionized energy, energy in and out in material change, energy activation, chemical energy  
- Energy from metabolism, ATP energy, energy for matter circulation, biological energy, light and chemical energy from photosynthesis  
- Energy from the interior of the Earth, mantle convection energy, energy from the ocean, earth formation energy, planet orbit energy, |
best way to give students experience needed to equip them with the competency of DC. We have decided which part of science curriculum to analyze and we selected all energy related content from K to 12 science curriculums. Our decision-making process about which grades and textbooks to analyze as described below.

Though students learn science at the elementary school level, they learn about ‘renewable energy’ in the sixth grade only. At the middle school level, no DC related renewable energy topics were found. In Grades 7 and 8 science textbooks, no topics related to energy were found. In Grade 9 science textbooks (the two most popular textbooks were selected for analysis), there were ‘energy’ topics found, but all of the topics were only related to scientific concepts. For example, students were asked the question; How does kinetic energy change when the swimmer jumps higher? This question can require students to experience ‘logical thinking’, but we decided not to include it for analysis because it is not connected to climate change issue. Another example that we decided to exclude in the analysis, is an activity of designing a manual fan powered by the self-generating energy of a bike. As all of energy related content in the Grade 9 science textbook was related to the concept of ‘energy’ itself, but not renewable energy. Therefore, the topic of energy from middle school science textbooks was excluded as data in this study.

**Table 3** Energy content included in the high school integrated science textbooks

| Level | Science curriculum |
|-------|--------------------|
| High school level (Grade 10 integrated science and experiment textbooks) | 4. Environment and energy |
| | 4.1. Ecosystem and environment |
| | – Energy conversion and preservation |
| | – Global warming and climate change |
| | – Energy conversion and efficient use |
| | – Light, electricity, heat, potential, motion, chemical, wave energy |
| | 4.2. Power generation and renewable energy |
| | – Renewable energy housing |
| | – Thermal, hydro, solar, nuclear power |
| | – Comparison of thermal power generation and nuclear power generation |
| | – Efforts for zero-carbon cities |
Technology textbooks were also reviewed and while there was some material related to the topic of ‘energy’, such as, how to make a ‘solar heat cooker’. However, we decided to exclude the energy topics from other subjects (like technology textbooks) in this study. Energy content connected to the environment was found for Grade 10 textbook. For example, students in Grade 10 learn (Table 3) energy concepts connected to climate change, zero-carbon cities, efficient energy use, and the comparison of energies, all of which could inspire DC. The Grade 10 content was significant (see Table 3), however, the content specific science textbooks for Grades 11 and 12, no energy topics related to climate change were identified, so these books were not analyzed in this study. Through this selection process, only the content from the Grade 6 and Grade 10 integrated science textbooks remained.

### 3.3 The Development of Energy Related Democratic Citizenship Inclusive Energy Topic STEAM Books

After identifying what content was being taught at each grade level, we developed a new series of energy-related DC inclusive STEAM books containing topics of renewable energy topics related to nuclear, wind power, thermal, and solar energy. The books were developed on the basis of our experience as science educators with expertise in STEAM. STEAM is the combination of science, technology, engineering, art, and mathematics through which students learn science concepts from their curiosity, apply them for solving problems, and experience emotional aspects. STEAM Education is an approach to teaching and learning that combines science, technology, engineering, the arts, and mathematics to guide student inquiry, discussion, and problem-solving. Education experts say STEAM education is about more than developing practical skills alone (Sim et al., 2015). The books were designed as reading books with simple activities rather than as activity books. Renewable energy was selected as the topic as this issue is familiar and can be interesting to students due to its importance for Korea and the wider world. The process of developing these energy-related STEAM books for DC consisted of (1) develop guidelines on how to implement components of DC in STEAM books, for example, we made a cartoon (describing what energy issue related problems we face on TV) in order to motivate students to feel ‘sympathy’ (motivation chapter). There is also a card activity where students can recognize the pros and cons of each energy use for the future, and where students also experience ‘critical thinking’ (pros and cons chapter). We developed six or seven chapters for each energy topic in four STEAM books. (2) We selected four different energy topics and made four energy related DC inclusive STEAM books with informative resources for the purpose of DC inclusion in the context of science.
3.4 The Validity Construction of Democratic Citizenship Inclusive STEAM Books

To construct the validity of the energy related DC inclusive STEAM books, we engaged 13 teachers as consultants to respond to a survey which was designed to check the content validity of developing DC inclusive STEAM books and provide feedback on the potential effectiveness of their use in and out of schools. The 13 teachers in this study first came to learn what DC is, what kinds of DC components there are, and their definitions. Second, the consultants were given the STEAM books to review and to use the DCF to identify what kinds of DC components were included. Third, the consultants checked whether each energy topic in the STEAM books included appropriate DC components in each chapter as designed by the researchers. Their responses were used to revise the STEAM books to be used as the supplemental materials for equipping students/citizen with DC competencies in the context of science.

We discussed the consultants’ responses with each other and followed up with discussions when needed. When we shared the opinion of what components of DC in each STEAM book could be included in each chapter, we agreed to select the most frequently shown component of DC. For example, one researcher selected the most frequently used DC components as critical thinking, social accountability, and communication and collaboration in the first chapter of nuclear energy and another researcher selected critical thinking, social accountability, and self-directed competency, and then we agreed to select the two most frequently shown components of DC.

4 Results

In this section, we share the findings of our analysis of the textbooks and we provide examples of how the results of this analysis were used to develop a series of energy-related books using the STEAM approach to teach renewable energy topics that are aligned to different components of the DCF we constructed. Specifically, in this section we describe the frequency that the eight DC components were identified in relation to this content in textbooks in grades 6–12. We analyzed what kinds of DC components could be found and which were missing and we calculated the frequency and percentage appearance of each DC component at different grade levels. We also provide some examples from the texts to demonstrate how the DC components were applied. Following this, we share details about the development of the four DC-Inclusive STEAM Energy books we developed using our framework. We provide detailed descriptions of the book contents and map the content to the included DC components.
Finally, we share the feedback gathered from teacher experts who used the DCF to analyze our books and offer suggestions for improvement.

4.1 **Analysis of DC Inclusion Energy Content in Science Textbooks**

In Korea, all textbooks must be approved by the Ministry of Education and they are developed to align to the national curriculum. First, the data analysis of DC in textbooks were from national elementary school textbooks and lab books. All elementary students in Korea use only one kind of national textbook, and students start to learn science using individual science textbooks from third grade. In addition to science textbooks, students at elementary school experience scientific inquiry activities in science lab books, which accompany the science textbooks. Therefore, analysis of DC representation in science textbooks and lab books at the elementary level was conducted. The Grade 6 textbook and lab book analyzed in this study was published by KOFAC (2015). Second, the analysis of DC representation at the high school level was conducted using an integrated science textbook and the accompanying lab book for Grade 10 (published by Shin et al., 2017; Sim et al., 2017). Textbooks at the secondary level in Korea are published different publishers, but they must all be approved by the MOE through strict evaluation.

4.1.1 Elementary Levels

Thirty-two DC components in one Grade 6 science textbook and 23 DC components in one science lab book (KOFAC, 2015) were identified and analyzed (Table 4). First, critical thinking (CT) and social accountability (SA) in DC were the most often found, science, technology and society (STS) and decision-making (DM) were less frequently found, and sympathy (S) was missing in the science textbooks. Second, information management (IM) was the most commonly found, self-direction (SD) was less frequently found, and sympathy (S), STS, and decision-making (DM) were missing in science lab books. To provide more context for the overall assessment, an example of analysis results from one national textbook and lab book for Grade 6 are also shared (Figure 1).

| Source       | CT | CC | IM | S | SA | STS | SD | DM | Total |
|--------------|----|----|----|---|----|-----|----|----|-------|
| Textbooks    | 9  | 5  | 5  | 0 | 9  | 1   | 2  | 1  | 32    |
| Lab books    | 5  | 4  | 7  | 0 | 5  | 0   | 2  | 0  | 23    |

Table 4: The frequency of DC Components related to energy topic in Grade 6 textbooks and lab books.
CT, CC, IM, and SA were found relatively more often than STS, SD, and DM in textbooks as well as lab books. There were more IM components of DC in lab books with activities than textbooks, but there were no STS and DM in lab books at all. S (sympathy) was not found in textbooks and lab books at elementary level (Figure 1).

Figure 2 provides an example from a textbook in which students are supposed to select a place to investigate the current energy use in their schools (for instance, the classroom, the bathroom, or dining hall). The students are asked to collect data to decide if the energy use in the selected place is efficient or to offer better ideas of how the efficiency could be improved. In this activity, students develop a catalogue or video scenario for the promotion of efficient energy use. In this activity, students investigate the energy situation of their school (relevance, data collection) and take on individual roles such as journalists and experts (cooperative learning) to perform activities such as whether energy is effectively used or not (logical judgment) and how (alternative search).

Our analysis of this activity shows that IM (information management), CT (critical thinking), DM (decision-making), and CC (communication and collaboration) components of DC are present. This activity ‘Think Together’ in the textbook is connected to a practical activity in the lab book. Not all activities in the lab books are connected to those in the textbooks, but some of them are strongly connected. Students design a concrete plan, such as which parts of
the school, students would choose to study energy efficiency, how they would improve energy efficiency, and how they would make a video about energy efficiency. During this activity, students would experience diverse IM (information management) and SD (self-directed planning) components of DC.

4.1.2 Middle School Levels
As introduced in the methodology section there were no concrete activities for students to experience DC explicitly from the Grades 7–9 textbooks. The textbooks cover only energy related scientific concepts like gravitational energy or kinetic energy etc., as follows from two popular textbooks.

Earthquake energy, light energy, friction energy, energy circulation, temperature energy, thermal energy, wave energy, respiratory energy, light energy, chemical reaction energy, energy entering and leaving the earth, radiation energy, chemical reaction energy, animal energy, sea temperature solar energy
While there were a few tangentially related energy concepts in the textbooks, as they were not related to climate change topics, they were excluded from analysis. For Grades 7–9, two popular science textbooks were selected. These books included some reading activities like DM (decision-making) where students plan to find out how potential energy changes when a swimmer dives from a high place. However, this was not considered as data to be analyzed in this study, since this content is not related to DC. Another example from a middle school science textbook includes an activity entitled, *Let's check the power consumption of electrical appliances around us directly or through internet*. This activity is related to the energy transformation and conservation unit, but it is not related to DC; therefore, we decided not to include it for data analysis. In the middle school textbook, all activities are related to energy concepts rather than energy issues. Thus, no DC components were identified in the middle grades’ science texts.

4.1.3 High School Levels (One General Science Book for Grade 10)

There were 178 examples of DC found in two textbooks and 72 in two accompanying lab books (Table 5). First, CC (communication and collaboration) was the most often found, whereas SA (social accountability), DM (decision-making), and S (sympathy) were less frequently found in the textbooks. Second, CC (communication and collaboration) was the most commonly found and S (sympathy) was less frequently found in the lab books. To provide more context for the overall assessment, an example of analysis results from two Grade 10 textbooks and two Grade 10 lab books (Shin et al., 2017; Sim et al., 2017) is provided in Figure 3.

The common patterns of DC inclusions from the two selected textbooks and lab books showed CC (communication and collaboration) and IM (information

| Source          | CT | CC | IM | S | SA | STS | SD | DM | Subtotal |
|-----------------|----|----|----|---|----|-----|----|----|----------|
| Textbook 1      | 9  | 35 | 28 | 1 | 5  | 7   | 5  | 2  | 92       |
| Textbook 2      | 16 | 28 | 16 | 0 | 6  | 8   | 8  | 5  | 86       |
| Lab book 1      | 2  | 13 | 4  | 0 | 3  | 2   | 4  | 4  | 32       |
| Lab book 2      | 1  | 10 | 8  | 2 | 6  | 3   | 4  | 6  | 40       |

Note: Grade 10 integrated science textbooks and lab books (textbook 1 & 2, lab book 1 & 2).
management) very highly found. The DC components at the high school level included the missing/limitedly shown S (sympathy). Figure 4 shows an example of identified DC components from a Grade 10 integrated science textbook (Shin et al., 2017; Sim et al., 2017). The activity title is “Solving it on your own”, where students are asked to know and analyze what kinds of energy they use in daily life and what energy could come alternative sources, such as solar or nuclear. Students are expected to propose a new plan about how to use nuclear energy in the Korean economy.

In this analyzed example, the DC components of SD (self-directed planning), DM (decision-making), and STS (science, technology, and society) were found. Another example from the textbook is one activity named as “Self-solved” where students write a news article on the amount and efficiency of electricity produced in power plants after visiting them in the community. Students could experience the SA (social accountability) and IM (information management) components of DC.

Another example from an integrated lab book activity called “Designing a sustainable, eco-friendly energy city”, where students investigate eco-friendly cities by role-playing as different city-planners to collect data to draw a blueprint...
1. **(understand)** Let’s distinguish between solar energy being directly converted and used as an energy resource after being converted and accumulated.

2. **(apply)** Find examples of solar energy used in architecture, mining, agriculture, sterilization, and explain the energy conversion process.

3. **(creativity & integration)** To find out the current level of technology in convergence development, let’s write an article investigating nuclear fusion devices developed at home and abroad and evaluate their feasibility.

**FIGURE 4** Example of DC components identified in a Grade 10 integrated science textbook

Note: Analysis revealed that the following DC components are included:
Self-directed planning (SD), Decision-making (DM), and Science, technology, and society (STS).

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for sustainable eco-friendly energy cities they want to live in, and predict the anticipated effects of their plans in the green cities. During this activity, students could experience the DC components of CC (communication and collaboration), IM (information management), SA (social accountability), and SD (self-directed planning).

A third example includes having students needing to investigate how to devise a zero-energy house and improve each part to reduce the use of fossil fuels in their homes. The students should decide how to produce energy and discuss matters to consider in designing housing to power the house. On the basis of this discussion, students are asked to draw and present a diagram of their team’s zero-energy house. Lastly, students evaluate the zero-energy houses from the different perspectives of individuals, society, and the Earth. From this activity, students can experience IM (information management), CC (communication and collaboration), and DM (decision-making) components of DC.
Generally, CC (communication and collaboration) and IM (information management) occurred relatively more often than CT (critical thinking), SA (social accountability), STS (science, technology, and society), SD (self-direction), and DM (decision-making) in the selected integrated science textbooks and lab books in this study. There was only one instance of S (sympathy) in textbook 1 and only two in lab book 2 of integrated science about DC. This result shows that it must be difficult to make activities where students feel ‘sympathy’ from studying energy issues.

### 4.2 Development of the Energy Topic DC Inclusive STEAM Book

After analyzing the various textbooks and lab books for DC components, we worked to develop a new series of energy-related books using the STEAM approach to teach renewable energy topics related to nuclear, wind power, thermal, and solar energy, so that citizens as well as students can learn and experience DC inclusive content more easily. STEAM/STEM programs have dominated educational policy nationally and internationally, and we had previously noted that SSI/global issues are very appropriate for STEAM programs (Park, 2020, 2021). Our goal was to develop a book with simple activities so people (family at home, people at library, or students at school) could easily read the content and cultivate DC competencies related to energy issues.

In each STEAM book, first, we tried to motivate the students to have an interest in each energy topic by using the TV news or some cartoon-based dialogue amongst students or family about how to save energy or what renewable energy is preferable in each country. This encompassed the ‘A’ as liberal arts (including language art, fine art, or physical art) in STEAM. Second, students can learn scientific concepts mainly in introduction of each book where we described what each energy is, how it works, how much of it is used, and where the energy is generated nationally and internationally. These sections incorporate scientific concepts to represent ‘S (science)’, and students have chances to experience other components, such as ‘T (technology)’, ‘E (engineering)’, and ‘M (mathematics)’, implicitly in each book. Third, energy issues are introduced for students to experience the pros and cons of each energy topic. This activity, known as argumentation, represents another component of ‘A’ in STEAM as language arts. Fourth, students experience the nature of science where they can learn about scientists’ attitudes in history or attitudes toward the science like energy use in the community. With this guide, we tried to contain all five components of the interdisciplinary STEAM parts in each STEAM book.

Table 6 shows the guideline for developing an energy DC inclusive STEAM book. We discussed what content of each energy topic is appropriate for each component of DC. For example, the inclusion of CT (critical thinking) could be
| Component                                      | Content to be included                                                                                                                                 |
|------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Critical thinking (CT)                        | Construct content to identify pros and cons based on evidence of how they conceive each energy. Present relevant information supporting by evidence when presenting scientific concepts |
| Communication and collaboration (CC)          | Participants discuss and share their opinions (on a student basis at school, on a visitor basis at a science museum, or on a family basis at home) when asked questions, simple card games, or activities are presented |
| Information management (IM)                   | Present analysis with tables and graphs of domestic and foreign energy-related current status and changes. The way of transition from solar energy, the energy efficiency on the basis of pros and cons |
| Sympathy (S)                                  | Experience the attitude of scientists in history given in cartoons and metaphors, or various influences on humans in energy-related societies          |
| Social accountability (SA)                    | Make people feel personally responsible by recognizing problems associated with energy-related individual lives |
| Science, technology, and society (STS)        | Identify how the development of energy-related technology affects society or how society affects the development of technology |
| Self-directed plan (SD)                       | Specific personal actions that can take the initiative in planning and implementing issues that need to be addressed in energy-related content |
| Decision-making competency (DM)               | If there is a conflict or dispute over energy issues, it is necessary to present the final opinion by discussing it on a family or a colleague basis |
corresponding to how much each energy usage could be efficient when compared to other energy sources on the basis of the pros and cons. For another example, the inclusion of IM (information management) could correspond to scientific concepts or information like the method of transition to solar energy, its principle for producing energy, and the current status quo of energy use nationally and internationally. More information from the guideline which we developed is found below in Table 6. We used this guideline to develop the energy topics in each chapter of the DC inclusive STEAM book.

4.3 Examples of Democratic Citizenship-Inclusive Energy Topics in STEAM Books

Next we made DC-inclusive STEAM books on energy topics for citizens and students. For each STEAM book, we sought to motivate students to have interest in each energy topic by using cartoons based on news from TV or dialogues common in families about how to save energy or describing what renewable energy is preferable in different countries, including Korea. Each book was planned so that students learn scientific concepts by being introduced to a type of energy, including how it works, how much it is used, and where and how it is generated. This way, in addition to scientific concepts, students have a chance to implicitly experience the technology, engineering, and mathematics aspects of STEAM. Next, the energy issues are introduced for students to experience the pros and cons of each topic, which involves the language art of argumentation. Finally, students are encouraged to reflect on the nature of science by being introduced to how scientists’ and peoples’ attitudes about energy use in the community has changed over time. In the sections that follow, we highlight the content and the DC components targeted for each book.

4.3.1 Nuclear Energy DC Inclusive STEAM Book

Table 7 provides an overview of the Nuclear Energy DC-Inclusive STEAM book. In this book, all of the DC components except SD (self-directed) plan are included. Safety issues have been mentioned for nuclear energy, which is widely utilized in Korea, but considering the eco-friendly part and efficiency, we emphasized the chance of identifying the pros and cons of denuclearization and included reading and simple activities (card game) to increase understanding of nuclear energy.
### Table 7: Description of the nuclear energy DC inclusive STEAM book

| Chapter | Title                                                   | Content                                                                 | DC          |
|---------|---------------------------------------------------------|-------------------------------------------------------------------------|-------------|
| CH1     | Motivation (I am very curious about nuclear energy)     | Students can be motivated by a cartoon addressing a father and son having a conversation about what nuclear energy is on TV | CC/SA       |
| CH2     | The trends of nuclear energy nationally and internationally | Students can learn concepts about nuclear energy                        | STS/CT      |
| CH3     | Two faces of nuclear energy                            | There are positive and negative issues in society, about nuclear energy so students can experience these two aspects by activities or reading | S/STS       |
| CH4     | What is my opinion?                                    | Students in groups face real issues which they need to make decision about in their society | IM/CC/CT    |
| CH5     | My emotional travel with nuclear energy                | Students learn where they can be most exposed to radiation (exposure to cigarette smoke due to radioactivity of smoke particles) | SA/S        |
| CH6     | If I were Einstein? Marie Curie?                       | What could I have done? Students can experience scientists’ attitude about their work. What would I do if I were a scientist in history? Could I change society if I were them? | S           |

Note: CT (critical thinking); CC (communication & collaboration); IM (information management); S (sympathy); SA (social accountability); STS (science, technology, and society); SD (self-directed planning); DM (decision-making).

#### 4.3.2 Wind Power Energy DC Inclusive STEAM Book

Wind power is considered one of Korea’s main renewable energy sources. In particular, due to Korea being surrounded by the sea on three sides, it is advantageous to use the sea as a wind power generation complex. Therefore, the installation of domestic wind power generation is increasing. The advantages and disadvantages can be seen in Table 8. All DC components except SD (self-directed planning) are included. Since this STEAM book is mainly for reading...
| Chapter | Title                              | Content                                                                                                                                                                                                 | DC       |
|---------|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| CH1     | Energy appropriate for Korea       | There is a motivation to find out what renewable energy is suitable for Korea. As climate change issues emerge, we introduce in cartoons what energy-oriented conversions are taking place in major countries. | CT/SA    |
| CH2     | Current status at home and abroad  | In the United States and Germany, where wind power is increasing, wind power is used more often than solar energy. In other words, the proportion of renewable energy in major countries is gradually shifting to solar and wind power. Including the case of Denmark. | STS/CT   |
| CH3     | Duality of wind power              | Wind power has its advantages in Korea, but in the case of disadvantages, what are the issues and problems?                                                                                         | S/STS/DM |
| CH4     | Wind, catch me                     | Introducing what can be easily done with wind energy-related activities. It is possible to use these as family-level or self-directed learning.                                                     | IM/CC/CT/SA/DM |
| CH5     | Wind power plant market and supply | In addition to determining if there are any political, economic, and other problems in installing a wind farm, find solutions by looking at the reactions of residents when constructing a wind farm. | SA/S     |
| CH6     | Wind power and scientific history  | Learn the attitudes of scientists by finding out the history of wind-related flights.                                                                                                               | S/STS    |

Note: CT (critical thinking); CC (communication & collaboration); IM (information management); S (sympathy); SA (social accountability); STS (science, technology, and society); SD (self-directed planning); DM (decision-making).
and doing simple activities, there is no chance for the readers/students to experience the SD component of DC.

4.3.3 Thermal Energy DC Inclusive STEAM Book

Thermal power generation has been continuously pointed out as a problem due to the depletion of fossil fuels and the emission of greenhouse gases and harmful substances caused by the use of fossil fuels, and thermal power plants using fossil fuels are gradually disappearing from the world. Table 9 shows efforts to

| Chapter | Title | Content | DC |
|---------|-------|---------|----|
| CH1     | Motivation. (Thermal power generation that leaves a carbon footprint) | A carbon footprint calculator is introduced, and the relationship between the amount of carbon dioxide generated and aspects of life, such as the use of electricity, gas, water, and transportation, is introduced. In connection with this, it is possible to pay attention to the problem of greenhouse gas emissions caused by thermal power generation, and to think about the problems of thermal power generation. | SA/CT |
| CH2     | Current status at home and abroad | The current status of thermal power generation is checked through domestic and international data on thermal power generation. The current status of thermal power plants in Korea are investigated and issues related to domestic thermal power plants are reviewed. | IM/SA |
| CH3     | Pros and cons of thermal power generation | Exploration activities to understand the advantages and disadvantages and principles of thermal power generation. | STS/IM |
Table 9 Description of the thermal energy DC inclusive STEAM book (cont.)

| Chapter | Title                                      | Content                                                                 | DC       |
|---------|--------------------------------------------|-------------------------------------------------------------------------|----------|
| CH4     | CH4 Thermal energy and climate crisis      | Cartoons discussing the relationship between the use of thermal energy and climate change. (Including greenhouse gas emissions and anger over fine dust). | STS/CT   |
| CH5     | CH5 How to reduce fossil fuel use          | Let’s look at efforts to reduce fossil fuel use for decarbonized and carbon-free, | DM/S     |
| CH6     | CH6 Carbon emission trading companies      | Understand the meaning of carbon emission rights and discuss the role of future jobs, carbon emission trading companies. | SA/STS/DM|

Note: CT (critical thinking); CC (communication & collaboration); IM (information management); S (sympathy); SA (social accountability); STS (science, technology, and society); SD (self-directed planning); DM (decision-making).

reduce fossil fuel use and learn more about thermal energy through the essential role of carbon emission trading companies. All DC components except CC (communication & collaboration) and SD (self-directed) are included. Unlike other STEAM books, there are no card games or simple activities where readers as a family or students in a group share opinions, so there is no chance of CC. This STEAM book does not have an opportunity for SD either.

4.3.4 Solar Energy DC Inclusive STEAM Book
People generate electricity directly from solar power by installing solar panels on houses and apartments. Readers can investigate the domestic situation of solar energy use and discuss what efforts to overcome the shortcomings of solar power generation are critical (Table 10). All DC components except SD are included. Since this STEAM book is mainly for reading and doing simple activities, so there is no chance for the readers/students to experience the SD component of DC.

All of the energy topics STEAM books covered all the DC components except SD (self-directed). These STEAM books were designed for self-reading not as a
## Table 10 Description of the solar energy DC inclusive STEAM book

| Chapter | Title                                    | Content                                                                                                                                                                                                 | DC          |
|---------|------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| CH1     | My house’s roof is a solar power plant   | Examining domestic solar panel installation support policies and discusses advantages and problems of solar panel installation.                                                                     | CT/SA/CC    |
| CH2     | Current status at home and abroad        | It examines the current status of solar energy at home and abroad. Various data to find out about the situation of solar power generation in Korea can be reviewed, and the future of solar energy generation can be considered through large-scale solar energy generation cases. | IM/SA       |
| CH3     | Electricity from solar power?            | Explore the knowledge of various areas to understand the principle of solar power generation. We look at the scientific characteristics of light energy and thermal energy from the sun to Earth. | IM/CT       |
| CH4     | Photovoltaic devices                     | Explore the photoelectric phenomenon and the principle of solar cells, and understand the characteristics of solar devices.                                                                            | STS         |
| CH5     | How to install solar cells               | Learn the relevant knowledge and functions necessary to install solar cells at home, and make cell phone charging devices with solar power.                                                          | DM/S        |
| CH6     | Efforts to use the sun                   | Review various efforts to overcome the shortcomings of solar power generation and think about future solar power generation.                                                                          | IM/SA/CT    |

Note: CT (critical thinking); CC (communication & collaboration); IM (information management); S (sympathy); SA (social accountability); STS (science, technology, and society); SD (self-directed planning); DM (decision-making).
workbook, so we interpreted that it was not easy to include a chance where students could plan to take any action involving energy issues explicitly. These STEAM books are designed as mainly reading activities rather than doing activities. The results of this section confirmed that it is possible for us to employ the guidelines (Table 6) to develop energy related DC inclusive STEAM books. The distribution of DC usage from four energy related DC inclusive STEAM books appear below (Table 11).

In general, the inclusion of DC components in the four energy-related STEAM books was appropriate for each energy topic and each chapter of each topic. The most frequently used DC component was social accountability at 23.2% (13/56) and the second was critical thinking at 17.9% (10/56), followed

| DC component                          | Nuclear energy | Wind power energy | Thermal energy | Solar energy | Total |
|---------------------------------------|----------------|-------------------|----------------|--------------|-------|
| Critical thinking (CT)                | 2              | 3                 | 2              | 3            | 10    |
| Communication and collaboration (CC)  | 1              | 1                 | 0              | 1            | 3     |
| Information management (IM)           | 2              | 1                 | 2              | 3            | 8     |
| Sympathy (S)                          | 3              | 3                 | 1              | 1            | 8     |
| Social accountability (SA)            | 4              | 3                 | 3              | 3            | 13    |
| Science, technology, and society (STS)| 1              | 3                 | 3              | 1            | 8     |
| Self-directed plan (SD)               | 0              | 0                 | 0              | 0            | 0     |
| Decision-making competency (DM)       | 1              | 2                 | 1              | 1            | 6     |
| Total                                 | 14             | 16                | 13             | 13           | 56    |

(100%)
by information management at 14.3% (8/56), sympathy at 14.3% (8/56), and science, technology, and society at 14.3% (8/56). As these STEAM books were designed for self-reading rather than as workbooks, we felt that it was not easy to include a chance for students to plan to take any action involving energy issues explicitly. For this reason, the books do not include the component of self-directed planning. Instead, we designed the STEAM books to promote mainly reading and thinking activities. However, we agreed that if there is a given situation and the main character has to solve energy-related problems in any chapter in the given situation, this could be used for the readers to implicitly experience self-directed plan. The relatively low frequency of communication and collaboration inclusion came from the fact that these DC STEAM books were developed for the use of reading purpose rather than doing.

**Table 12** Consultant responses for the inclusion of DC components for each STEAM book

| Topic               | CH | Agreement (%) | Comment | Final modification                      |
|---------------------|----|---------------|---------|----------------------------------------|
| Nuclear energy      | 1  | 100           |         |                                        |
|                     | 2  | 92.3          | +S/+STS | Additional +S/+STS                     |
|                     | 3  | 92.3          |         |                                        |
|                     | 4  | 84.6          |         |                                        |
|                     | 5  | 100           | +IM     | Additional +IM                          |
|                     | 6  | 100           |         |                                        |
| Wind power energy   | 1  | 92.3          |         |                                        |
|                     | 2  | 53.8          | -CT     | Need to redefine CT                    |
|                     | 3  | 84.6          | +CT     | Additional +CT                          |
|                     | 4  | 76.9          |         |                                        |
|                     | 5  | 61.5          | -S/+STS | Accept -S/+STS                          |
|                     | 6  | 92.3          |         |                                        |
| Thermal energy      | 1  | 92.3          |         |                                        |
|                     | 2  | 94.6          |         |                                        |
|                     | 3  | 46.1          | -IM/+STS| Accept -IM/+STS                         |
|                     | 4  | 69.2          | -CT/+STS| Accept -CT/+STS                         |
|                     | 5  | 69.2          | -S/+STS | Accept -S/+STS/ and -CC/+IM             |
|                     | 6  | 100           |         |                                        |
4.4 Validation of DC Inclusion STEAM Books by Experts

We invited 13 teachers to serve as experts to provide content and face validity checks concerning the appropriateness of the DC components provided in each of the four books related to energy (nuclear, wind power, thermal, and solar). The 13 panelists’ agreement or disagreement responses for the DC inclusion from each energy topic were collected and analyzed as follows (Table 12).

From the 24 chapters developed for the four books (six chapters per book), the teachers strongly agreed with the DC component inclusion in 15 chapters (average more than 80%). However, nine chapters had less agreement (below 80%, shown with bold numbers in Table 12). Teachers suggested deleting the DC component of critical thinking (53.8% agreement among 13 teachers) from Chapter 2 in the wind power energy STEAM book. In this case, we discussed and decided to redefine critical thinking so that the teachers could better understand why critical thinking was included in the Chapter 2. For Chapter 3 from the thermal energy STEAM book, there was agreement of only 46.1% among the 13 teachers about DC components, and some teachers suggested removing the critical thinking component and adding the science, technology, and society component to the chapter.

We discussed the removal and addition of these DC components as suggested by the teachers and decided to accept their suggestions. While discussing the teachers’ responses from the survey for constructing validity, we confirmed the following points needed to be modified in each energy-focused STEAM books (Table 13).
Table 13  Content to be included after validity construction process

| Issue to be addressed | Content to be considered for modification |
|-----------------------|------------------------------------------|
| Critical thinking (CT) definition | The teachers and researchers had different understandings about critical thinking (CT). In this study, CT consists of both divergent thinking and logical thinking. Some understood that CT is mainly logical. Therefore, we confirmed that CT includes both divergent and logical thinking. |
| Information management (IM) definition | When data related practices are offered explicitly, then we considered that there is an IM component. Some teachers felt that IM practices were offered implicitly which means that every teacher could interpret them differently. Therefore, we confirmed that explicitly given data practices are considered IM. |
| Sympathy (S) definition | The learners/readers can share sympathy with the given situation explicitly or implicitly. |
| Limitations for developing STEAM books | This STEAM books were developed with more reading activities rather than doing activities so there is limitation in including more active DC component such as CC, SD, and DM. Energy related DC inclusive STEAM programs can include much more CC, SD, and DM in doing activities. |

Note: CT (critical thinking); CC (communication & collaboration); IM (information management); S (sympathy); SA (social accountability); STS (science, technology, and society); SD (self-directed planning); DM (decision-making).

5 Conclusions and Implications

In this study, we developed a framework and employed it to what components of DC were already included in science textbooks or lab books used in grades 6–12 in Korea. The DC framework consists of eight components: critical thinking; communication and collaboration; information management; sympathy; social accountability; science, technology, and society; self-directed planning; and decision-making. We investigated energy topics in elementary and secondary level science textbooks and lab books to see if any DC component could be found in those books. We selected topics in energy in the science curriculum
because they are appropriate for fostering DC education. We found there were differing levels of inclusion of each component of DC at the elementary and high school textbooks and lab books, but there were none in the middle school textbooks and lab books. Our analysis of the middle school materials revealed that while there were several chances for students to think critically or to make plans about how to save energy, the activities tended to involve questions focused on energy concepts (such as potential energy and kinetic energy).

Our application of the DCF was useful for determining whether any DC components were included and which were included most often. Since there has been research showing that students can think logically and make evidence-based decisions more often when presented with SSI and can solve those issues more actively, it is critical for students to experience SSI so that they can improve their reflective thinking and problem-solving skills (Kolstø, 2008; Millar & Osborne, 1998). From this point of view, the development of the DCF in this study is very timely, and the DCF can be used to determine whether any SSI books or related content is appropriate to help students experience DC, which is an essential competency for the next century. Especially, it is recommended that science educators who are developing science curriculum and writing science textbooks should include SSI to help foster DC in students. It is pivotal to include SSI in science textbooks for students to be exposed to, think about, and take action towards solutions to SSI. Each DC component can be learned when students engage in practices necessary to face SSI and make decisions to solve problems. It will be essential for policy makers to include DC learning opportunities in the curriculum. Students need to learn DC explicitly when exposed to all the different SSI in the world. Students and citizens need to form and hold a firm world view (Wahono et al., 2021; Zeidler et al., 2019).

In this study, we developed four energy topic DC-inclusive STEAM books (on the subjects of nuclear energy, wind power energy, thermal energy, and solar energy) for citizens and students to experience rich DC. However, there were limitations for including all DC components into each book. For example, self-directed plans were missing in all four energy topic DC-inclusive STEAM books since those STEAM books did not encourage readers to make their own plans for solving issues. However, we offer that this can be addressed in the future as self-directed plans could be included as stories where the readers indirectly experience the perspective of a main character who must make plans before taking action about energy issues. As there were limitations in constructing energy topics that had various activities that the students could carry out themselves, for the future, we think it would be beneficial to develop four energy-related DC-inclusive STEAM books with activity-focused STEAM
programs that have more activities for students to actively share ideas and take actions to work on solving the problems of SSIs.

While established the construct validity for applying the DCF to analyze the DC components in the STEAM books we developed by engaging expert teachers to give their recommendations. We found we need to collect more opinions about the eight DC components. We believe that if teachers understand the DC components well enough, they can be confident to teach SSI lessons with the aim of fostering students with DC competencies (Luft, 1999; Mansour, 2009; Pajares, 1992). Teachers' understanding can bring DC practices into the classroom. There was some disagreement among teachers when defining critical thinking, which is one component of DC. The interpretation about critical thinking by teacher experts could be different due to the following two reasons. First is that teachers may not understand CT completely and may form different interpretations based on their implicit understandings. Therefore, it is essential to teach the DC components so the teachers have a firm understanding. Teacher experts who participated in the validation process responded that equipping students with the competencies of DC is critical and it was very helpful to learn DC in science education is and to understand how DC can be included in the classroom. Thus, it would also be reasonable to teach the DC components to students through more explicit methods rather than implicit (Barruè & Albe, 2013; Bell et al., 1998; Khishfe, 2013; Sengul, 2019).

We believe that more training is needed for science educators to understand DC, to develop DC educational programs, and to be able to construct consensus about DC's definition for its usage in education. Science educators need to collaborate with teachers so that they can understand DC and implement their practices on the basis of their understanding. We argue that to implement DC teaching and learning in the classroom, teachers should use SSIs, like energy topics related to climate change, so that students can be familiar with how to deal with global issues in this world. Educators in science museums can also perform the same roles for citizens to be exposed to SSIs in their daily lives so they can also target the development of DC components within informal education settings. We conclude by urging science educators to develop systematic professional development programs in which science educators collaborate with teachers to interact with each other to develop expertise in DC.

**Abbreviations**

| DC  | Democratic Citizenship |
|-----|------------------------|
| DCF | Democratic Citizenship Frame |
Acknowledgements

This work was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2021R1F1A1045468).

Ethical Considerations

The data reported in this study does not require human subjects’ approval. The data was generated text analysis and feedback from expert panelists for construct validation process. No individual data was collected or reported on that will risk the safety, identity, and confidentiality of anyone.

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