



BRILL



brill.com/apse

# Deriving the Key Competencies Required as an Extreme Citizen Scientist

*Ji Hye Kwon*

Department of Earth Science Education, Seoul National University,  
Seoul, 08826, Republic of Korea

*shpower66@snu.ac.kr*

*Hyun-Jung Cha* | ORCID: 0000-0002-9492-4954

Department of Science Education, Chuncheon National University  
of Education, Chuncheon, 24328, Republic of Korea

*todd0906@snu.ac.kr*

*Seo-Ha Na* | ORCID: 0000-0003-0483-6457

Department of Science Education, Seoul National University,  
Seoul, 08826, Republic of Korea

*seoha7892@snu.ac.kr*

*Hyejin Um*

Gorim Middle School, Yongin, 17151, Republic of Korea

*uhjo616@snu.ac.kr*

*Sung-Eun Lim* | ORCID: 0000-0002-0987-0534

Department of Science Education, Seoul National University,  
Seoul, 08826, Republic of Korea

*skyblue8435@snu.ac.kr*

*Changmi Park* | ORCID: 0000-0003-3651-4620

Seoul Yangmok Elementary School, Seoul, 08021, Republic of Korea

*cmipark@snu.ac.kr*

*Seok-Hyun Ga* | ORCID: 0000-0002-1226-7381

Science Education Center, National Taiwan Normal University,  
Taipei City, 106, Taiwan

*shga89@naver.com*

*Chan-Jong Kim* | ORCID: 0000-0002-0976-5283

Corresponding author

Department of Earth Science Education, Seoul National University,

Seoul, 08826, Republic of Korea

*chajokim@gmail.com*

Received: 21 September 2022 | Revised: 13 November 2022 |

Accepted: 13 November 2022

## Abstract

Citizen science is expected to play an important role in relation to scientific literacy Vision III for students living in the future society. This study aims to identify the characteristics of extreme citizen science (ECS) and extreme citizen scientists (ECSs) and to derive key competencies of ECSs using literature analysis from Korean and international educational contexts. The characteristics of ECS are identified were as follows: Citizens recognize problems, set research topics, establish data collection plans to solve them, analyze and interpret collected data, and conduct social action. Three categories of key competencies for ECSs were derived: Thinking scientifically with appropriate knowledge, exploring as knowledge producers, and acting while considering both individuals and communities. The results of this study can be used for developing citizen science competency measurement tools, development of ECS programs, and training of ECSs. Implications for future research are considered.

## Keywords

extreme citizen science – extreme citizen scientist – characteristics of extreme citizen science – extreme citizen scientist performance – key competencies of extreme citizen scientist

## 1 Introduction

In 1982, the European Union adopted guidelines for the control of major risk facilities, commonly known as the Seveso Directive, due to accidents at chemical sites that had occurred during the previous decade, especially those at Flixborough in 1974 and Seveso in 1976 (Irwin, 1995). In 2011, a nuclear power plant exploded in Fukushima, Japan, and the resulting pollutants are still causing a great deal of damage to citizens. In addition, problems arising from

the development of science and technology such as the humidifier disinfectant incident in Korea in 2016, insecticide eggs, and the sanitary pad carcinogens incident in Korea in 2017 (Lee, 2018) have become too easy to find. In addition, as the level of science and technology has increased, the complexity of the problem also increased. With the rapid development of science and technology, we enjoy a rich and convenient life, but at the same time, various problems caused by the developing science and technology coexist.

As it can be drawn from the past incidents and current circumstances described above, the potential and unpredictable risks of modern society are deeply related to the development of science and technology. German sociologist Beck (1992) described this society as a “risk society.” Citizens living in a risk society as democratic citizens are essentially required to have the ability to manage risks they may encounter. Citizens must participate in communication related to the development of science and technology, and because technological innovation has a profound impact on their lives, it is important for citizens to have adequate scientific literacy. Roberts (2011) classified the areas constituting scientific literacy into knowledge and application. In addition, scientific literacy focused on science itself, such as the on the structure of science and scientific knowledge, was defined as “Vision I,” and the scientific literacy required for the use of scientific knowledge in everyday life and decision making on individual and social issues related to science and technology was defined as Vision II. Sjöström (2017) proposed a scientific knowledge Vision III and classified it into a Vision IIIA emphasizing sociopolitical behavior and a Vision IIIB emphasizing a moral-philosophy-existential perspective.

As society changes in this way, understanding of scientific literacy is also developing, and it is very important to foster scientific literacy from the perspective of Vision III as a citizen living in a risk society. However, the experience provided to students in current school science education is somewhat focused on developing a scientific literacy Visions I and II. In this context, citizen science is expected to provide implications for cultivating scientific literacy Vision III in school science education. Early citizen science simply helped citizens collect data from scientists under the leadership of professional scientists. However, due to the improvement of citizens’ education levels and social and technical changes such as electronic communication, citizens’ ability to contribute to science projects has increased rapidly, leading to a new era of citizen science (Park, 2018). As a result, citizen science has also changed qualitatively and quantitatively from the past (Haklay, 2015). Now, extreme citizen science (ECS), in which citizens not only serve as assistants to scientists but also collaborate with scientists to set up research questions to collect, analyze, and participate in science-related social actions, is considered important (Haklay, 2013). As extreme citizen scientists (ECSS), citizens not

only participate in scientific exploration that begins with simple curiosity, but also become subjects to solve various social problems such as socioscientific issues (SSI). Therefore, citizens' participation in scientific activities emphasized in ECS can be a good role model for fostering scientific literacy Vision III in school science education. The experience of participating in ECS at the time of first encountering science was not only the basis for participating in various citizen sciences even as an adult, but also the educational effect was high when citizen science projects were combined in the middle and high school curriculum (European Commission, 2013, p. 14). In other words, in order for the public to continuously participate in ECS, the ECS experience in adolescence is very important, and it is necessary to provide related experiences in school science education. However, the research of scientific activities to develop scientific literacy Vision III in school science education is limited, especially from the perspective of ECS (Park, 2022). Therefore, in order to develop and apply programs and teaching strategies that reflect ECS in the school, it is necessary to identify the characteristics of ECS and the activities of ECSs. In addition, It is necessary to identify the key competencies to be equipped as ECSs in the flow of cultivating key competencies for students living in the society of the future.

To this end, this study aims to summarize the characteristics of ECS and ECSs, and to specify the key competencies for ECSs required to provide ECS experiences in school science education. Specific research questions are as follows:

1. What are the characteristics of extreme citizen science and extreme citizen scientists?
2. What are the key competencies required as an extreme citizen scientist?

## 2 Literature Review

### 2.1 *Vision of Scientific Literacy and Key Competencies*

Science literacy (SL) has already begun to be mentioned in the 1950s, and since then, many scientists, science educators, and science policy makers have accepted the importance of SL as they have introduced SL into a new curriculum (Park, 2016). However, the perspective on how to view SL varies depending on scholars. The reason is that SL is socially constructed and can change according to social situations or times (Choi et al., 2011), and scientists and science educators, as well as scientific sociologists, social scientists, and non-formal science educators, can emphasize the importance of SL from different positions (Laugksch, 2000).

Roberts (2011) argued that there are two conflicting perspectives about the term SL, and so Roberts further divided the constituents of SL into knowledge

and application. The scientific literacy focused on the science itself, such as the structure of science and the core concepts and principles of scientific knowledge, was named Vision I. Vision II was defined by the scientific literacy required to use scientific literacy in everyday life and make decisions on individual and social issues related to science and technology, such as the ability to explain and understand the effects of science and technology on daily life. Sjöström (2017) agreed with Roberts (2011)'s SL Vision I, II and proposed SL Vision IIIA and IIIB, which add relatively less-emphasized sociopolitical behavior and moral-philosophy-exist perspectives in the existing SL, continuing Roberts' (2011) research. As the SL vision changed in this way, the main goals of science education were also expanded.

In line with these social changes, the curriculum was also expanded the previous educational goal from curriculum-oriented education to capacity-building education. Taking the Organization for Economic Co-operation and Development (OECD) Definition and Selection of Competencies (DeSeCo) project (OECD, n.d.) as a turning point, they developed a competency-based curriculum in earnest. In the OECD DeSeCo project, competency was defined as "the ability to meet complex demands successfully through the mobilization of mental prerequisites" (Rychen & Salganik, 2003, p. 4). In particular, the OECD defined key competency as meeting the following criteria among various competencies: "(1) contribute to desired outcomes in terms of an overall successful life and a well-functioning society, (2) apply across contexts and domains (3) and are important to all individuals for coping successfully with complex demands" (Rychen & Salganik, 2003, p. 4) Furthermore, the OECD saw the need for fundamental reflection on the purpose and method of education, and through the OECD Education 2030 Project (2019a), they re-recognized the competencies necessary for students to lead their lives well in the society of the future. OECD Education 2030 (2019a) explained three aspects of the context of social change that requires setting new educational objectives: environmental, economic, and social. It predicted that the changes in the society of the future will show the characteristics of uncertainty, unpredictability, well-being, tolerance, and pursuit of fairness, unlike the paradigms of success, efficiency, and economic growth that people have focused on since the industrial era. The OECD stated that "the concept of competency implies more than just the acquisition of knowledge and skills; it involves the mobilization of knowledge, skills, attitudes and values to meet complex demands" (OECD, 2019a, p. 11) and they defined three transformative competencies that students need to change society and shape the future for a better life, including "creating new value, reconciling tensions and dilemmas, and taking responsibility" (OECD, 2019b, p. 4).

This trend has led to attempts to design curriculums based on key competencies worldwide (Kwak et al., 2014; So et al., 2010). The New Zealand government

revised its curriculum based on the key competencies proposed by the OECD's DeSeCo project and announced a new national curriculum in 2007, presenting five core competencies (thinking; using language, symbols, and texts; managing self; relating to others; and participating and contributing) (Boyd & Watson, 2006). In addition, through science education, the government provides meaningful experiences for students to develop five key competencies from the New Zealand curriculum (New Zealand Ministry of Education, 2007). The Australian curriculum presented seven general capabilities (literacy, numeracy, ICT capability, critical and creative thinking, personal and social capability, ethical understanding, and intercultural understanding) and the science curriculum introduces science inquiry skills in four areas: questioning and predicting, planning and conducting, processing and analysis data and information, and communicating (Australian Curriculum Assessment and Reporting Authority, 2016).

The curriculum presented by the Ministry of Education (MOE) in Korea revealed that the characteristics of the 2015 revised curriculum are as follows: "Based on the educational ideology and desirable human character that has been pursued in Korean curriculums to date, [the curriculum] focuses on cultivating creative convergence talents with the good habits and key competencies required by the society of the future" (MOE, 2015a, p. 2). In the 2015 revised curriculum, six general competencies throughout the curriculum are selected and presented as key competencies, and key competencies for each subject are also presented in detail. The six general competencies that apply to all subjects and students are "self-management competency, knowledge-information processing skills, creative thinking skills, aesthetic-emotional competency, communication skills, and civic competency. The key competencies of science are scientific thinking ability, scientific inquiry ability, scientific problem-solving ability, scientific communication ability, and scientific participation and lifelong learning ability" (MOE, 2015b, pp. 3–4).

The international perspective on these competencies and the purpose of science education that has changed according to the context of social change have the same context as SL Vision III, which emphasizes the action and practice of science. For example, based on understanding of science, investigating in science, and communicating in science, the New Zealand curriculum aims to develop an understanding of socioscientific issues in the context of participating and contributing (New Zealand Ministry of Education, 2007). Also, through the inclusion of "civic competency" in key competencies presented in Korea's 2015 revised curriculum overview and "scientific participation and lifelong learning ability" in science and key competencies, the importance of SL Vision III will likely increase in the ever-changing society of the future. In this regard, citizen science is expected to play an exemplary role in cultivating SL Vision III.

## 2.2 *Citizen Science*

According to the Oxford English Dictionary (2014), citizen science is defined as scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions. That is, citizen science implies that anyone can participate in scientific research regardless of a person's background, education, and political beliefs. Although the phrase "citizen science" seems to have only appeared in modern society, it is actually as old as Aristotle (Bonney & Dickinson, 2012). In other words, the term "citizen science" itself may be relatively unfamiliar, but it can be said that the history of citizens practicing citizen science is very long. Citizen science has recently attracted more attention as the vision of scientific literacy develops. Citizen science can provide citizens with opportunities to cultivate scientific literacy and key competencies in a society where unpredictability is increasing will continue to increase with the development of science and technology (Krasny & Bonny, 2005; Science Communication Unit, 2013). Citizen science provides more observers and ideas for science projects, promotes environmental awareness, and saves overall scientific research costs. In addition, learning more knowledge of science and scientific research courses can strengthen scientific literacy, connect scientists and citizens, promote pleasant experiments, and establish social practices for the public good (Avard & Clark, 2001; Fazio & Karron, 2015; Pate et al., 2015).

Citizen science has significance not only in scientific aspects but also in other aspects. In a 2013 report released by the European Commission (EC), four aspects of the value of citizen science were described: scientific, educational, social, and policy. Citizens who participated in specific citizen science projects were able to promote scientific knowledge in the related field. In particular, when citizen science projects were combined with the middle and high school curriculum, the educational effect was high (EC, 2013, p. 14). In addition, through research led by local communities and environmental justice movements, citizens can get an opportunity to influence local policy decisions. Through this, public health, quality of life, social solidarity, and awareness of local problems and networks can be improved (EC, 2013, p. 16). Last, citizen science is also valuable in terms of policy, providing policymakers with evidence to support compliance with regulations in the industrial and commercial sectors and to continually gather information for future policymaking. Citizen science can also provide services to citizens by solving environmental problems that directly affect citizens on a regional, national, and global scale and providing opportunities to influence decisions on these issues (EC, 2013, p. 16).

The various ways citizen science is being used as explained above show its different classifications. The classification criteria can involve the goals of a citizen science project or the degree of citizen participation. In order to

understand citizen science from the perspective of Vision III, which emphasizes the importance of citizens' sociopolitical behavior, a classification system based on the level of citizens' participation in science projects is appropriate. Haklay (2013) divided citizen science into four levels based on the participation of citizens and the degree of activity performed.

The first level is the crowdsourcing stage, with citizens' participation at the lowest level. Citizens play a role as scientists' "sensors" and help them with simple computing tasks such as data classification. The second level is the distributed intelligence stage, where citizens provide their thoughts and opinions to projects that seek various people's perspectives and opinions. The third level is the participatory science stage. In this stage, citizens actively participate in research, even taking part in defining research issues and collecting data. The last is the ECS stage, in which citizens go beyond simply participating to establish cooperation with scientists. They work together throughout the whole level, from defining research problems to collecting and analyzing data.

Bonney and Dickinson (2012) classified citizen science into three categories: contributory, collaborative, and co-created. First of all, the contributory category accounts for the largest portion of citizen science projects so far, in which scientists lead projects while citizens make contributions to the work of scientists. In addition to contributing to data collection, citizens also disseminate the data analysis and results to their neighbors. Unlike the first category, the collaborative category is not solely led by scientists but involves both scientists and citizens in science projects. Citizens even participate in research design. From data analysis and interpretation to dissemination of research conclusions and results, the entire process is carried out in the form of collaboration. The co-creative category has the highest level of citizen participation. Citizens participate in all stages, from defining research questions to answering new questions. The co-creative category can be regarded as being in line with Haklay's (2013) "extreme citizen science." One distinctive characteristic of the classification of Bonney and Dickinson (2012) is that citizens perform "result propagation" activities that Haklay does not address.

English et al. (2018) accepted the concept of Den Broeder et al. (2018) and summarized the level of citizen science in the form of pyramids. They looked at citizen science from the standpoint of citizen's "participatory research." They explained that participatory research has the potential to democratize the research process and challenge the "knowledge monopoly," in which only the elite gain strength, by opening the scientific process to meaningful participation of people directly affected by the study. They divided citizen science into three stages according to the increment of public involvement in the study.

In the first step, citizens only participate in data collection, and their activities are sometimes active but passive as well. The second is a limited



participatory research stage in which citizens participate in defining research problems and collecting data. On the top of the pyramid, the third stage has the highest level of citizen participation. This stage is defined as ECS. In the ECS stage, citizens even play a role in setting their own research issues, participating in both data collection and analysis, and informing the public of the knowledge gained. The pyramids of English et al. (2018) followed Haklay's (2013) four-step classification of citizen science, however, English combined the first and second stages of Haklay into one primary stage. Activities such as public action were in the last, ECS stage. The researchers' classification of citizen science is summarized in Table 1.

TABLE 1 Classification of citizen science by researchers

Haklay (2013)	Bonney & Dickinson (2012)	English et al. (2018)
<i>Level 1. Crowdsourcing</i>		
a. Citizens as sensors	<i>Contributory:</i> Citizens contribute to data collection, analyze data, and disseminate results.	<i>Crowdsourcing and volunteered geographic information:</i> Participate in data collection only (actively or passively)
b. Volunteered computing		
<i>Level 2. Distributed intelligence</i>		
a. Citizens as basic interpreters		
b. Volunteered thinking		
<i>Level 3. Participatory science</i>		
Participation in problem definition and data collection	<i>Collaborative:</i> Citizens analyze samples and data, sometimes help with research design, interpret data, conclude, and spread results.	<i>Limited participatory research:</i> Participate in problem definition and data collection
<i>Level 4. Extreme citizen science</i>		
Collaborative science: problem definition and data collection and analysis	<i>Co-created:</i> Citizens participate in all stages of the project. Question definition, hypothesis development, outcome discussion, and answers to new questions.	<i>Extreme citizen science:</i> Participate in problem definition, data collection, analysis and interpretation, study dissemination, and public health action

To summarize the research results presented by those scholars, ECS means the stage of citizen science classification where the level of citizen participation is highest. In addition, in this stage, citizens independently participate in the entire research process. They do not stay at the level of citizen science under the guidance of scientists. Different scholars have different descriptions of what phrase, the entire research process, means. However, in general they all agree that it means citizens take part in a broad range of science research from defining research questions to data collection and analysis, beyond simple data collection. In addition, citizens in ECS participate in “hypothesis setting and research design,” “research conclusions,” and “social action” (Bonney et al., 2009; Bonney & Dickinson, 2012; Haklay, 2013). Here, all citizens who conduct such ECS are called “extreme citizen scientists.”

### 3 Methods

#### 3.1 *Procedure of Research*

The purpose of this study was to identify characteristics of ECS and ECSS and to derive the key competencies required as ECSS. For this research purpose, a literature analysis was conducted based on the competency development model of the International Board of Standards for Training, Performance, and Instruction (IBSTPI; Klein et al., 2004), which is regarded as useful for developing components of teaching competency (Jin & Rha, 2009) in two phases. The IBSTPI model consists of three stages: (1) literature analysis and data collection, (2) competency identification and estimating reliability, and (3) competency modification and final approval.

The purpose of the first literature analysis was to summarize the definition and characteristics of ECS, and to organize the activities performed by ECSS. Therefore, the first phase had three steps: (1) A literature analysis for ECS was conducted by the first author, (2) the characteristics and activities of ECS were identified by the ECS education group (ECSE group), and (3) reliability was discussed during lab seminars. The purpose of the second literature analysis was to use the results of the first literature analysis to derive the key competencies required as ECSS from the literature that presents various key competencies for students to develop. Therefore, the second phase had five steps: (1) A literature review and analysis was conducted for the various key competencies required of students, (2) key competencies required as ECSS were identified by ECSE group, (3) reliability was discussed during lab seminars, (4) key competencies were identified and final approval was given by the ECSE group, and (5) reliability was discussed during lab seminars.

The ECSE group consisted of seven people: three schoolteachers attending master's programs, two in doctoral programs, and two with doctoral degrees in science education. In lab seminars, 14 colleagues usually participated, including the ECSE group. In addition to the ECSE group, seven colleagues attending the lab meetings were four doctoral students, two master's students, and a professor in science education.

The study was conducted from December 2020 to December 2021. After formulating research questions in December 2020, a literature search and reading was done for 6 months. The first phase of literature analysis was conducted from June to July 2021, and the second phase continued from August 2021 to December 2021. The review by the ECSE group and lab seminars were held approximately every 2 weeks.

### 3.2 *Selection of Publications*

Korean and international literature was searched and analyzed for each research question. For the first research question, Korean literature published from 2000 to 2021 was searched with keywords such as “citizen science,” “future citizen science,” and “extreme citizen science” in academic research information services DBpia (<https://www.dbpia.co.kr>), Scholar (<http://scholar.dkyobo.co.kr>), and RISS ([www.riss.kr](http://www.riss.kr)). About 2,100 documents were found, but most simply contained “citizen” and “science” in their titles. There were only 40 documents dealing with “citizen science” in the academic sense corresponding to this study. Among them, four research articles dealing with the concepts and classification of citizen science in detail were selected. An international literature search was conducted with keywords such as “citizen science” and “extreme citizen science” on Google Academic Search (<https://scholar.google.co.kr>). About 478,000 documents were found. Among them, literature specifically covering the concept and classification of citizen science according to research subject were first selected, and then those with larger numbers of citations were finally selected. Literature simply providing the results of applying citizen science to scientific inquiry was excluded. Fourteen international documents were selected by focusing on literature dealing with “extreme citizen science.” The list of the resulting literature is summarized in Table 2.

For the second literature search, the same websites as the first were used. Among literature published from 2000 to 2021, those including keywords such as “competency,” “key competency,” “citizen science competency,” “citizen scientist competency,” “action competency,” “environmental competency,” and “civic competency” were searched on the Korean websites. More than 21,000 studies were found, but the academic field was narrowed down to pedagogy. Among them, those outlining the competencies that students should

TABLE 2 List of literature for first research question

Irwin (1995)	Citizen Science: A Study of People, Expertise, and Sustainable Development
Bonney et al. (2009)	Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy
Wiggins & Crowston (2011)	From Conservation to Crowdsourcing: A Typology of Citizen Science
Rowland (2012)	Citizen Science Goes “Extreme”
Stevens et al. (2014)	Taking Participatory Citizen Science to Extremes
Haklay (2015)	Citizen Science and Policy: A European Perspective
Eitzel et al. (2017)	Citizen Science Terminology Matters: Exploring Key Terms
Kim & Park (2017)	Citizen Science
Wildschut (2017)	The Need for Citizen Science in the Transition to a Sustainable Peer-to-Peer Society
Den Broeder et al. (2018)	Citizen Science for Public Health
English et al. (2018)	From Crowdsourcing to Extreme Citizen Science: Participatory Research for Environmental Health
Kim (2018)	Citizen Science Stories in Korea: 1982–2018
Park (2018)	The Current State and Tasks of Citizen Science in Korea
Park & Kang (2018)	Environmental Problems, Citizen Knowledge, and Citizen Science: Chance and Challenges of Citizen Science in Environmental Problems
Phillips et al. (2019)	Engagement in Science Through Citizen Science: Moving Beyond Data Collection
Fan & Chen (2019)	Citizen, Science, and Citizen Science
Pejovic & Skarlatidou (2020)	Understanding Interaction Design Challenges in Mobile Extreme Citizen Science
Skarlatidou et al. (2020)	Experiences from Extreme Citizen Science: Using Smartphone-Based Data Collection Tools with Low-Literate People

cultivate were selected. Literature describing the key competencies for middle and high school students was selected, while studies involving college students and professionals were excluded. Five Korean documents were selected, focusing on the literature that specifically explained each sub-element of competency. These documents included reports issued by government-funded

research institutes that study and implement the domestic curriculum and educational evaluation and were cited in the majority of domestic literature searched with the above keywords. For searching international literature, Google Scholar was used with keywords combining the words “competency,” “competency,” “key competency” with the words “citizen science,” “education,” “action,” and “civic education.” More than 1 million documents were found, but most of the documents were excluded after applying the same criteria as the Korean literature search. Among the remaining, six English documents that specifically presented sub-elements of each competency and were frequently cited in other documents were selected (Table 3).

TABLE 3 List of literature for the second research question

Jensen & Schnack (1997)	The Action Competence Approach in Environmental Education
Weinert (1999)	Concepts of Competence
Breiting & Mogensen (1999)	Action Competence and Environmental Education
Jensen (2004)	Environmental and Health Education Viewed From an Action-Oriented Perspective: A Case From Denmark
Lee et al. (2008)	A Study on the Vision of the Elementary and Secondary Curriculum to Improve the Key Competencies of Koreans in the Future: Focus on Setting Sub-Elements by Key Competency Area
Wilson-Hill et al. (2008)	Action Competence in New Zealand Schools: Improving the Capacity for Understanding Student Learning in EFS
Mogensen & Schnack (2010)	The Action Competence Approach and the “New” Discourses of Education for Sustainable Development, Competence and Quality Criteria
Kim et al. (2013)	A Study for Developing Student Competency Index
Choi et al. (2014)	Promoting Core Competency Education and Building Innovative Learning Ecosystems for Fostering Talent for the Future
Seo (2017)	An Exploration of Competencies in the 2015 Revised National Curriculum for the “Environment” Subject
Yun et al. (2018)	Identifying and Applying Components of Five Scientific Core Competencies in the 2015 Science Curriculum

### 3.3 Analysis

The purpose of the first literature analysis was to identify the characteristics of ECS from the literature and describe the specific activities of ECS. To this end, the perspective towards citizen science and specific scientific activities of citizens in the ECS stages in each article were identified and summarized (Table 4). Terms were coined for the activities repeatedly observed throughout the analysis and were then arranged in Table 4 for comparison.

Some activities, such as, “research problem definition,” “data collection,” and “data analysis” were explicitly included in all studies; however, “hypothesis setting and research design,” “research conclusion,” and “social action” activities were expressed in some studies. The ECSE group reviewed the data from the first round of literature analysis and comparison and then identified the characteristics and activities of ECS.

The goal of the second phase was to derive the competencies for ECS activities from the studies. An analysis framework was created with ECS activities identified from the first phase (Table 5). On the vertical axis, the activities of ECS200as are located. On the horizontal axis, the serial number of reviewed documents is placed to identify any competencies that matched to the activities from the literature. The competencies found in the reviewed literature for each ECS activity were listed and described in the table by the first author.

Dozens of competencies were identified through this process, but many of them seemed to overlap with one another. The ECSE group reviewed and

TABLE 4 Comparison of extreme citizen science activities in related studies

Activities Scholars	Research problem definition	Hypothesis setting, research design	Data collection	Data analysis	Research conclusion	Social action (spread the results)
Bonney and Dickinson (2012)	✓	✓	✓	✓	✓	✓
Roy et al. (2012)	✓	✓	✓	✓	✓	✓
Haklay (2012)	✓		✓	✓		
Skarlatidou et al. (2020)	✓		✓	✓		
Den et al. (2018)	✓		✓	✓	✓	✓
English et al. (2018)	✓		✓	✓	✓	✓

TABLE 5 Analysis framework for competency extraction

Serial number of literature ECS activities	No. 1	No. 2	No. 3
	Problem recognition Research problem definition Research plan establishment Data collection Data analysis Research conclusion Problem resolution plan Social action		

discussed the competencies identified and tried to reduce overlaps among them. The results were reported and discussed during lab seminar. During the lab seminar, we received feedback that the 10 competencies seemed to be general and represented the specific characteristics of the ECSs well.

The ECSE group worked on arranging the 10 competencies based on the characteristics of ECS (Table 8). As the 10 competencies tended to be complex constructs with various abilities, they seemed not to have clear and mutually exclusive boundaries, but rather overlapped with one another. After arranging them, some competencies, such as basic learning and tool utilization, were characteristics that came to be included in all competencies of ECS and were more general competencies, while some competencies were more related to the characteristics of ECS. For example, scientific inquiry, problem solving, creative thinking, and information processing competencies were identified as being close to scientific investigation. The ECSE group worked on deriving key competencies of ECSs from the integration of identified competencies.

In order to increase the credibility of the analysis, member checking was used throughout the analysis process. The results of the literature review by a researcher were reviewed by a group of researchers with background and experience in ECSE and then reviewed by wider group of laboratory members, and the analysis results were presented in science education conferences. In addition, feedback from peers who attended presentations about this research at domestic and international academic conferences were also considered and used to further revise the study.

## 4 Results of the Research

### 4.1 *Characteristics of Extreme Citizen Science and Extreme Citizen Scientists*

The first phase involved identifying the characteristics of ECS and sub-activities of ECSs. Three characteristics were identified: citizens participating in the production of scientific knowledge, social action to share the results and resolve the perceived problems, and collaborative relationships with others including scientists (Table 6).

Based on the characteristics of ECS, eight sub-activities of ECSs were identified: (1) problem recognition, (2) research problem definition, (3) research plan establishment, (4) data collection, (5) data analysis, (6) research conclusion, (7) problem improvement plan, and (8) social action. The scope and sequence of sub-activities may change depending on the characteristics of the ECS project and context (Table 7).

TABLE 6 The characteristics of extreme citizen science

---

#### The characteristics of extreme citizen science

---

1. Citizens themselves recognize problems, set research topics, establish data collection plans to solve them, collect data, analyze and interpret collected data. Through this process, citizens independently participate in the production of scientific knowledge.
  2. Social action is carried out to inform the research results or to solve the perceived problem.
  3. In the process of generating scientific knowledge, citizens may participate in collaborative relationships with scientists, but they may conduct research independently.
- 

TABLE 7 The sub-activities of extreme citizen scientists

- 
1. Develop curiosity about simple scientific subjects and identify and collect data through everyday sources to recognizing SSIs affecting society using one's own regional and cultural expertise, citizens recognize problems on their own.
  2. Determine the research topic for the recognized problem.
  3. Establish a research plan.
  4. Data is collected through scientific procedures according to the research plan.
  5. The collected data is analyzed.



TABLE 7 The sub-activities of extreme citizen scientists (*cont.*)

- 
6. The results are derived to make conclusions on the research topic.
  7. Think about ways to improve the problem recognized through research conclusions.
  8. Citizens act on their own or practice social action to improve perceived problems.
- 

#### 4.2 *Key Competencies of Extreme Citizen Scientists*

As reported previously, the ECSE group review in second phase (see Figure 1) identified and defined 10 competencies of ECSs (Table 8). The range of the competencies identified seems to be wide: more general (self-management, basic learning, communication, information utilization, and tool utilization), science related (scientific inquiry, problem solving, and creativity) and social (interpersonal, and social and civic).

The 10 competencies were reviewed by the ECSE group and lab members and were evaluated as being too general to represent the unique characteristics of the key competencies of ECSs. Reflecting on this feedback, the ECSE group decided to group the 10 competencies of ECSs based on the characteristics of ECS (Table 6) and “knowledge,” “function,” and “attitudes and values,” the competencies suggested by the OECD Learning Compass 2030 (OECD, 2019b). To distinguish the unique competencies of ECSs from the 10 competencies identified, the phrase “key competencies of ECSs” was used.

The three key competencies of ECSs identified were production of scientific knowledge, social action, and collaborating with scientists and others (Table 9). The first key competency of ECSs, production of scientific knowledge, was identified around the first characteristics of ECS (Table 6) and the skills and knowledge in competencies of OECD Learning Compass 2030. Among 10 competencies of ECSs, scientific inquiry, problem solving, creative thinking, and information processing were closely related. This key competency can be defined as the ability to conduct scientific inquiry on the relevant issues with generally ill-defined problems and uncertainties of knowledge.

The second key competency of ECSs, collaboration with scientists and others, was based on the collaborative relationship (Table 6). Among 10 competencies of ECSs, interpersonal, communication, social citizenship, and information processing were closely associated with this key competency. Some competencies, such as basic learning and tool utilization, seemed to be necessary to most of areas and related to all three key competencies. This key competency was defined as the ability to form and maintain constructive

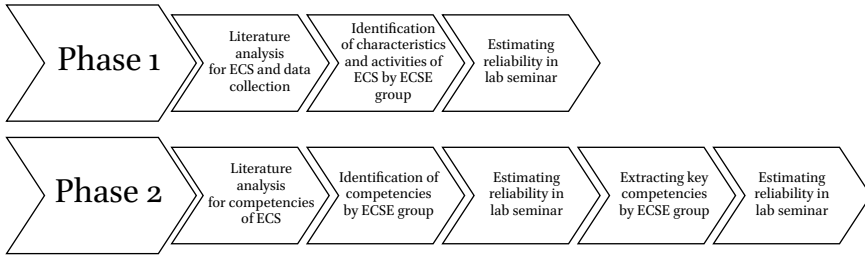


FIGURE 1 Research process using IBSTPI model

TABLE 8 The competencies of extreme citizen scientists identified from the literature

Competency	Definition
Scientific inquiry	The ability to set and control appropriate variables, design research logically and critically, conduct research according to scientific procedures, analyze data, and draw conclusions.
Basic learning	The ability to know the basic principles of the natural world and scientific principles and methods, including literacy, and to use them appropriately.
Communication	The ability to choose and express one's thoughts and emotions appropriately and to think and communicate from the perspective of others.
Interpersonal	The ability to cooperate with others for a common purpose and understand, consider, and resolve conflicts meaningfully and constructively with a tolerant attitude.
Problem-solving	The ability to clearly recognize problems to be solved, select appropriate information and data to solve them, present various ideas and solutions in consideration of various perspectives and interests, and select and practice the most reasonable of them.
Creative thinking	The ability to think critically, creatively, divergently, and innovatively, and in a way that allows for the integration of ideas so as to develop ideas in various ways and create new values.
Information utilization	The ability to have the ethical consciousness required to access and utilize information, collect and analyze necessary knowledge and information, select knowledge and information appropriately, and effectively utilize it.
Tool utilization	The ability to have knowledge of interactive language, text, ICT, etc. and to utilize them according to their purpose.

TABLE 8 The competencies of extreme citizen scientists identified from the literature (*cont.*)

Competency	Definition
Self-management	The ability to reflect on one's values and actions through reflective and reflective thinking, and to live self-directedly by clearly recognizing what one should do for one's life with self-identity and confidence.
Social and civic	The ability to actively participate in community development and take responsible actions with the values and attitudes required of members of local, national, and global communities based on the spirit of compliance, environmental consciousness, and ethical consciousness.

TABLE 9 Key competencies of extreme citizen scientists

Key competency	Definition
Production of scientific knowledge	The ability to conduct scientific inquiry on the relevant issues with generally ill-defined problems and uncertainties of knowledge.
Collaboration with scientists and others	The ability to form and maintain constructive interpersonal relationships and communicate effectively with scientists and colleagues for the common purpose of understanding and solving relevant socio-scientific issues.
Social action	The ability to actively participate in social and civic actions with problem solving competency in democratic ways.

interpersonal relationships and communicate effectively with scientists and colleagues for the common purpose of understanding and solving relevant socioscientific issues.

The third key competency of ECSs, social action, was searched around the second characteristics of ECS (Table 6), and the "attitudes and values" competency of the OECD Learning Compass 2030. Among the 10 competencies of ECSs, social citizenship, interpersonal, problem solving, and self-management competencies were more relevant to this key competency. The social action key competency was defined as the ability to actively participate in social and civic actions with problem solving competency in democratic ways.

## 5 Conclusion and Discussion

The purpose of this study was to use a literature review to identify the characteristics of ECS and to derive key competencies of ECSS to promote citizen science education and scientific literacy for future citizens. We draw our research conclusions as follows. First, the characteristics of ECS are as follows: (1) Citizens themselves recognize problems, set research topics, establish data collection plans to solve them, and collect, analyze, and interpret data. Through this process, citizens independently participate in the production of scientific knowledge. (2) Social action is carried out to inform the research results or to solve the perceived problem. (3) In the process of generating scientific knowledge, citizens may participate in collaborative relationships with scientists, but they may conduct research independently. Second, the sub-activities of ECSS are: (1) problem recognition, (2) research problem definition, (3) research plan establishment, (4) data collection, (5) data analysis, (6) research conclusion, (7) problem improvement plan, and (8) social action. These eight keywords were used to extract the key competencies of ECSS from the literature. Third, the three key competencies of ECSS are: (1) production of scientific knowledge, (2) collaboration with scientists and others and (3) social action.

Before this study, the key competencies for citizen science had not yet clearly been established. From literature reviews and expert discussions, three key competencies were established based on the characteristics and competencies of ECS identified in this study. As interest in citizen science projects has been increasing, efforts to prepare participants for citizen science have been attempted. Lorke et al. (2019) systematically investigated training needs for citizen science to develop competencies for citizen science projects for participants, facilitators, and project designers. They suggested three areas of needs: core, operational, and engagement. Each area provides practical aspects of training for participants. For example, core needs for participants include provision of a clear definition of citizen science, clear delivery of the scientific background of the project, and relevance of the project to the training audience. They can contribute to the practice of citizen science projects and to the preparation and input of the project; however, they do not describe the key competencies to be developed throughout the project. Our study can provide valuable information and direction on the goals of citizen science.

Blanco-Lopez et al. (2015) conducted a Delphi study to establish the key aspects of science competency for citizenship in Spain. Although this is not directly related to citizen science, it is of interest because it deals with science competency for citizenship, to which ECS is also very closely related. They

reported five aspects: critical attitude/thinking; individual responsibility; ability to search for, analyze, synthesize, and communicate information; ability to reason, analyze, interpret, and construct an argument in relation to scientific phenomena and knowledge; and ability to work as part of a team. Although they are different from the key competencies of ECS of our study in terms of the number and scope of each competency, there seems to be common ground. Individual responsibility may align to social action in ECS, and ability to work as part of a team is related to collaboration with others in ECS. The rest of the five are closely related to scientific knowledge production. As their science key competency was established for science education in general, they did not specify science-related social issues and collaboration with scientists as was done in the findings of this study.

In the international trend of key competencies in science education compiled by Koh and Jeong (2014), Australia and New Zealand reckon “personal and social competency” as one of the key competencies. As uncertainty and unpredictability increase in the future due to the development of complex science and technology, ECS becomes more important as the need of citizens’ participation in scientific issues increases. The importance of these competencies can also be found in the OECD 2030 project. The OECD Education 2030 project predicted that the society of the future where today’s students will live will have characteristics of uncertainty, unpredictability, well-being, tolerance, and fairness, unlike the paradigms of success, efficiency, and economic growth that have been noted since the industrial era. The context of social change is explained in terms of environmental, economic, and social aspects. It is also necessary to set a new educational purpose in the future (OECD, 2019). Against this background, scientific exploration should now have a different set of goals and competencies for science researchers and participating citizens. In this respect, ECS carries characteristics and fosters competencies that are most sought after in today’s society.

This study is based on a literature analysis, which has some limitations. First, since this study is an explorative study, which derives the key competencies required of ECSS from a literature analysis, the direction is different from the competency model developed by analyzing people with excellent competencies in the field, just as it is mainly used for competency development in the job field. In addition, some literature in which specific competencies were emphasized was excluded in order to increase objectivity and persuasive power in the process of selecting documents to be analyzed. This may affect the key competencies of ECSS. This study also adopted group discussion to identify the characteristics and key competencies of ECS. The members of the

group had strong backgrounds in and experience with ECSE; however, they also had limited experience with ECS. The characteristics of the ECSE group may have affected the findings of this study.

## 6 Implications for Practice and Future Research

Finally, this study has the following significance: While the vision of scientific literacy required by the public in a society where future uncertainty increases, attention was paid to extended civic science consistent with scientific literacy Vision III. In order to incorporate ECS into a competency-based curriculum, the key competencies required as ECSs were derived. Citizens' participation in scientific research and technological innovation is important. At a time when efforts to revitalize it are increasing, ECS seems to be an exemplary approach. This research achievement is of great academic significance in that it embodied the key competencies of ECSs.

With active international interest and research on key competencies in the education community, key competencies were set for both the overall curriculum in the Korea's 2015 revised curriculum and for each subject. This study can contribute to the elaboration of the concept of a key competency in that this study has established key competencies for ECSs that have not been developed so far.

The key competencies of ECSs presented in this study may suggest the direction of school science education to which the scientific literacy Vision III is applied. The research results of this study may be used to further research on the development of competency measurement tools to measure the key competencies of ECSs, the development of ECS programs, and textbooks. In addition, it seems necessary to conduct empirical research on the cultivation of students' competencies through the practical implementation of educational activities reflecting the key competencies of ECSs.

### Abbreviations

DeSeCo	Definition and Selection of Components
EC	European Commission
ECS	Extreme Citizen Science
ECSE	Extreme Citizen Science Education
EU	European Union
KC	Key Competency

OECD	Organization for Economic Cooperation and Development
SL	Science literacy
SSI	Socioscientific Issues

## Funding

This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Ministry of Science and ICT (NRF-2020R1A2C1014534).

## Ethical Considerations

Approval to conduct this study was granted by the Seoul National University Ethics Review Board. The data collected from this project were obtained with the necessary clearance from the school, guardians and the students involved in the study.

## About the Authors

**Ji Hye Kwon** is a secondary school earth science teacher and her master's degree from the Earth Science Education department at Seoul National University in Seoul, Republic of Korea. Her research focuses on the key competence of extreme citizen scientist at middle- and high-school level. She is particularly interested in extreme citizen science education on the subject of climate change.

**Hyun-Jung Cha** is a post-doctoral researcher in the Science Education Department at Chuncheon National University of Education, Republic of Korea. She received her bachelor's degree in Earth Science Education and master's degree and doctoral degree in Science Education from Seoul National University. Her research focuses on model-based science learning, science teacher expertise, science learning dealing with socioscientific issues, such as climate change. She is particularly interested in science learning using technology and science teacher expertise with respect to technology.

**Seo-Ha Na** works as an earth science teacher in South Korea and earned a master's degree in science education from Seoul National University. Her research

focuses on achieving teacher agency in the context of citizen science education using Arduino. She is interested in the ecological approach to teacher agency and citizen science education.

**Hyejin Um** is a science teacher at Gorim Middle School, Yongin, Republic of Korea. She received her bachelor's degree in Earth Science Education from Korea National University of Education, Cheongju, Republic of Korea, and a master's degree in Earth Science Education from Seoul National University, Seoul, Republic of Korea. Her research focuses on student identity and agency in citizen science club activities. She is particularly interested in the relationship between student identity and agency.

**Sung-Eun Lim** is an elementary school teacher and doctoral degree candidate in the Department of Science Education at Seoul National University in Seoul, Republic of Korea. Her master's degree research focused on model-based science learning, meta-modeling knowledge, and modeling performance. She is particularly interested in examining science education using Actor-Network Theory. Other central themes of her research are science learning using digital technology, agency, citizen science education, and socio-scientific issues, such as global environmental risk.

**Changmi Park** is a teacher in Seoul Yangmok Elementary School in Seoul, Republic of Korea. She holds a bachelor's degree in engineering from Ewha Womans University and also a bachelor's degree in elementary school education from Daegu National University of Education. And she holds a master's degree and a doctoral degree in Earth science education from Seoul National University in Republic of Korea. Her research focuses on scientific inquiry, STEM (STEAM) education, and Pedagogical Content Knowledge in science education using various technologies. Also, she is particularly interested in citizen science education in school context and Technology Embedded Scientific Inquiry (TESI).

**Seok-Hyun Ga** is a visiting assistant professor at the Science Education Center, National Taiwan Normal University. He holds a B.S. in Earth Science Education and Physics Education from Seoul National University (SNU), a B.S. in Computer Science from Korea National Open University, and an M.S. and Ph.D. in Science Education from SNU. His current research interests include technology-assisted science learning employing physical computing, internet of things, virtual reality, and augmented reality.



**Chan-Jong Kim** is Professor in the Department of Earth Science Education at Seoul National University in Seoul, Republic of Korea. He received his bachelor's degree in Earth Science Education and master's degree in Geological Sciences from Seoul National University in the Republic of Korea. He also holds a doctoral degree in Science Education from the University of Texas at Austin in the United States. His research focuses on scientific modeling as an approach to scientific exploration and learning in a variety of subjects, contents, and contexts and on development and application of various methods for the analysis of collective talk with learning of science. He is particularly interested in education for diverse learners in Korean K-12 on global environmental risks such as climate change.

### References

- Australian Curriculum Assessment and Reporting Authority. (2016). *The Australian curriculum*. Retrieved from <http://www.australiancurriculum.edu.au>.
- Avard, M. M., & Clark, B. K. (2001). Globe in preservice and inservice teacher education. *Journal of Geoscience Education*, 49(5), 461–466.
- Beck, U. (1992). From industrial society to the risk society: Questions of survival, social structure, and ecological enlightenment. *Theory, Culture & Society*, 9(1), 97–123.
- Blanco-López, Á., España-Ramos, E., González-García, F. J., & Franco-Mariscal, A. J. (2015). Key aspects of scientific competence for citizenship: A Delphi study of the expert community in Spain. *Journal of Research in Science Teaching*, 52(2), 164–198.
- Bonney, R., Cooper, C., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K., & Shirk, J. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience*, 59(11), 977–984. <https://doi.org/10.1525/bio.2009.59.11.9>.
- Bonney, R., & Dickinson, J. L. (2012). Overview of citizen science. In J. L. Dickinson, & R. Bonney (Eds.), *Citizen science: Public participation in environmental research* (pp. 19–26). Cornell University Press.
- Boyd, S., & Watson, V. (2006). *Shifting the frame: Exploring integration of the key competencies at six normal schools*. Wellington: New Zealand Council for Educational Research.
- Choi, K., Lee, H., Shin, N., Kim, S., & Krajcik, J. (2011). Re-conceptualization of scientific literacy in South Korea for the 21st century. *Journal of Research in Science Teaching*, 48(6), 670–697.
- Den Broeder, L., Devilee, J., Van Oers, H., Schuit, A. J., & Wagemakers, A. (2018). Citizen science for public health. *Health Promotion International*, 33(3), 505–514. <https://doi.org/10.1093/heapro/daw086>.

- English, P. B., Richardson, M. J., & Garzón-Galvis, C. (2018). From crowdsourcing to extreme citizen science: Participatory research for environmental health. *Annual Review of Public Health*, 39(1), 335–350. <https://doi.org/10.1146/annurev-publhealth.040617-013702>.
- European Commission. (2013). *In-depth report: Environmental citizen science*. European Commission. [http://ex.europa.eu/environment/integration/research/newsalert/pdf/IR9\\_en.pdf](http://ex.europa.eu/environment/integration/research/newsalert/pdf/IR9_en.pdf).
- Fazio, X. E., & Karrow, D. D. (2015). The Commonplaces of Schooling and Citizen Science. In M. P. Mueller & D. J. Tippins (Eds.), *EcoJustice, citizen science and youth activism: Situated tensions for science education* (pp. 179–191). Springer.
- Haklay, M. (2013). Citizen science and volunteered geographic information: Overview and typology of participation. In D. Sui, S. Elwood, & M. Goodchild (Eds.) *Crowdsourcing geographic knowledge: Volunteered geographic information (vGI) in theory and practice* (pp. 105–122). Springer.
- Haklay, M. (2015). *Citizen science and policy: A European perspective*. Washington, DC: Woodrow Wilson International Center for Scholars.
- Irwin, A. (1995). *Citizen science: A study of people, expertise, and sustainable development*. Routledge. <https://doi.org/10.4324/9780203202395>.
- Jin, S., & Rha, I. (2009). A Framework of teaching competencies and comparison of the perception: between pre-service and in-service elementary school teachers in Korea. *The Journal of Elementary Education*, 22(1), 343–368.
- Klein, J. D., Spector, J. M., Grabowski, B., & Teja, I. D. L. (2004). *Instructor competencies: Standards for face-to-face, online, and blended settings*. Information Age Pub.
- Koh, E. J., & Jeong, D. H. (2014). Study on Korean science teachers' perception in accordance with the trends of core competencies in science education worldwide. *Journal of the Korean Association for Science Education*, 34(6), 535–547. <http://dx.doi.org/10.14697/jkase.2014.34.6.0535>.
- Krasny, M. E., & Bonney, R. (2005). Environmental education through citizen science and participatory action research. In E. Johnson & M. Mappin (Eds.), *Environmental education and advocacy: Changing perspectives of ecology and education* (pp. 292–320). Cambridge University Press.
- Kwak, Y., Son, J., Kim, M.-Y., & Ku, J. (2014). Research on ways to improve science curriculum focused on key competencies and creative fusion education. *Journal of the Korean Association for Science Education*, 34(3), 321–330.
- Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education*, 84, 71–94.
- Lee, H. J. (2018). *What is sSI education?* Seoul: PYMATE.

- Lorke, J., Golumbic, Y. N., Ramjan, C., & Atias, O. (2019). *Training needs and recommendations for citizen science participants, facilitators, and designers*. COST Action 15212 report. Natural History Museum. Retrieved from <https://nhm.openrepository.com/handle/10141/622589>.
- Ministry of Education (MOE). (2015a). *Korea national curriculum standards (2015–74)*. Ministry of Education.
- Ministry of Education (MOE). (2015b). *Korea national science curriculum standards (2015–74 [supplement 9])*. Ministry of Education.
- New Zealand Ministry of Education. (2007). *New Zealand primary and secondary (Level 1–8) curriculum*. New Zealand Ministry of Education.
- Oxford English Dictionary. (2014). *Citizen science*. Oxford: Oxford University Press.
- Organisation for Economic Co-operation and Development (OECD). (n.d.). *Definition and Selection of Competencies (DeSeCo)*. Retrieved from <https://www.oecd.org/pisa/definition-selection-key-competencies-summary.pdf>.
- Organisation for Economic Co-operation and Development (OECD). (2019a). *OECD future of education and skills 2030 – Concept note: Attitudes and values for 2030*. OECD. [https://www.oecd.org/education/2030-project/teaching-and-learning/learning/attitudes-and-values/Attitudes\\_and\\_Values\\_for\\_2030\\_concept\\_note.pdf](https://www.oecd.org/education/2030-project/teaching-and-learning/learning/attitudes-and-values/Attitudes_and_Values_for_2030_concept_note.pdf).
- Organisation for Economic Co-operation and Development (OECD). (2019b). *OECD future of education and skills 2030 – Concept note: Transformative competencies for 2030*. OECD. [http://www.oecd.org/education/2030-project/teaching-and-learning/learning/transformativecompetencies/Transformative\\_Competencies\\_for\\_2030\\_concept\\_note.pdf](http://www.oecd.org/education/2030-project/teaching-and-learning/learning/transformativecompetencies/Transformative_Competencies_for_2030_concept_note.pdf).
- Park, J. (2016). Discussions about the three aspects of scientific literacy: Focus on integrative understanding, settlement in curriculum, and civic education. *Journal of the Korean Association for Science Education* 36(3), 413–422. <http://dx.doi.org/10.14697/jkase.2016.36.3.0413>.
- Park, J. H. (2018). The current state and tasks of citizen science in Korea. *Journal of Science & Technology Studies*, 18(2), 7–41. DOI: 10.22989/jsts.2018.18.2.001.
- Park, C. (2022). *Students' experiences of scientific inquiry and transference during school citizen science program based on technology embedded scientific inquiry*. [Unpublished doctoral dissertation]. Seoul National University, Seoul, Republic of Korea.
- Pate, P. E., Guerrero, A., & Dobie, D. F. (2015). Carrizo Springs, Texas-The story of the Systems Academy of Young Scientists (SAYS). In M. P. Mueller & D. J. Tippins (Eds.), *Ecojustice, citizen science and youth activism: Situated tensions for science education* (pp. 223–245). Springer.

- Roberts, D. A. (2011). Competing visions of scientific literacy: The influence of a science curriculum policy image. In C. Linder, L. Östman, D. A. Roberts, P.-O. Wickman, G. Ericksen, & A. MacKinnon. (Eds.), *Exploring the landscape of scientific literacy* (pp. 11–27). Routledge.
- Rychen, D. S., & Salganik, L. H. (2003). *Highlights from the OECD Project Definition and Selection Competencies: Theoretical and Conceptual Foundations (DeSeCo)*. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago, IL.
- Science Communication Unit. (2013). *Science for environment policy in-depth report: Environmental citizen science*. University of West England, Bristol, England. Available at: <http://ec.europa.eu/science-environment-policy>.
- Sjostrom, J. (2017). Vision III: Framing STEM education with moral-philosophical-existential-political alternatives. Paper presented at the 12th Conference of European Science Education Research Association (ESERA), Dublin, Ireland.
- So, K. H., Lee, S. E., Lee, J. H., & Heo, H. I. (2010). Review on curriculum reform in the New Zealand: Implementation of key competencies-based curriculum. *Korean Journal of Comparative Education*, 20(2), 27–50.