Development and Impact of an Intercultural STEAM Program on Science Classroom Creativity

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Abstract

As collaboration among scientists from diverse backgrounds can help generate theories and foster the discovery of natural phenomena, the importance of creativity via collaboration in science learning has been widely recognized. This study aimed to investigate the science classroom creativity of Korean high school students who participated in an Australia-Korea intercultural STEAM program (ISP). Due to COVID-19 restrictions, data was only collected from Korean students. The Revised Science Classroom Creativity Questionnaire (R-SCCQ) was administered to 25 Korean students, and interviews were conducted with 10 students to explore creative behavior. The results showed a significant increase in students’ science classroom creativity following their participation in the ISP. This study shows that the intercultural experience provided by the program can help induce a more flexible mindset and encourage different perspectives, ultimately enhancing science classroom creativity. This finding
is significant as it highlights the potential of the ISP as a new teaching method for promoting creativity in science education.

Keywords

collaboration – creative behavior – intercultural activity – intercultural STEAM program – science classroom creativity

1 Introduction

Interest in scientific creativity has been growing recently in education circles. This form of creativity is one of the goals for the science, technology, engineering, arts, and mathematics (STEAM) system of science education. The acronym “STEAM,” formed from “STEM” with the additional ingredient of the arts, implies a program that focuses on and nurtures students’ artistic sensitivity, innovation, and creativity along with their understanding of STEM knowledge and skills (Sim et al., 2015). In this context, “arts” includes a wide range of liberal arts subjects including art, history, and literature (Yakman & Lee, 2012) and requires experience in various cultural fields. Many studies in Korea have reported STEAM education can be beneficial in helping promote students’ creativity (e.g., Kim & Choi, 2012; Lee et al., 2017). STEAM researchers in Korea have also shown strong interest in creativity as an important product of STEAM education (Kim & Kim, 2017).

In alignment with previous studies, this study focused on a STEAM program in a science class. This study’s research team created an intercultural STEAM program (ISP) by including intercultural interactions in which students could meet other students from different cultural backgrounds. Researchers have already reported that creativity can be effectively enhanced through interactions, communication, and cooperation with people from different geographical and cultural backgrounds (Dunne, 2017). The experience of diverse cultures has been reported to help reduce people’s prejudice against others, induce a more flexible mindset, and encourage different perspectives, which in turn enhance creativity (Chao et al., 2015; UNESCO, 2002). Maddux and Galinsky (2009) and Fee and Gray (2012) showed that intercultural experiences can have a positive effect on creativity by providing empirical evidence on the relation between creativity and a person’s adaptation to life in a country other than their home country. Leung and Chiu (2010) reported that students who had watched presentations of American-Chinese cultural fusion demonstrated
better creative performance than students who did not have such experiences. Thus, this study focused on the creative benefits of intercultural experiences in the field of science education and worked to develop an ISP that enriched the intercultural experience by emphasizing the interaction of group members from different backgrounds.

The theoretical framework of STEAM is the view that learning is a social constructivist activity (Chu et al., 2019; Holbrook et al., 2020). From the viewpoint of social constructivism, students learn through their interactions with teachers, colleagues, and the resource materials that they encounter. Students are expected to learn by interacting with their environment through things such as objects, sociocultural events, natural phenomena, and experimental results. These interactions, which are the foundation of any ISP, are effective not only in promoting students’ learning but also in fostering their creativity (Lee, 2015). Most intercultural programs, however, have been conducted within English language and literature classes or in global citizenship education (Lee et al., 2014), with the limited goals of helping students broaden their cross-cultural understanding and communication skills and their growth as global citizens (Wang, 2011; Yang et al., 2018). Unfortunately, there have been few studies of the role of intercultural programs in fostering creativity in science or STEAM classrooms (e.g., Lee, 2015), even though scientists typically generate theories and discover natural phenomena in collaboration with others who hail from diverse cultural and scholarly backgrounds (Simonton, 2004; Siau, 1995). Considering that modern science evolves scientific knowledge through such cooperation, science education should also pay attention to creativity achieved through interaction with peers (Song & Na, 2014). Therefore, more research is needed on intercultural science programs and intercultural STEAM programs in order to foster creativity in the science education field.

This study aimed to explore whether an ISP could be a good way of fostering creativity in science classrooms. To achieve this aim, the research team developed an ISP targeting high school students in Korea and Australia and examined its impact on scientific creativity. The researchers defined creativity in science classrooms based on the science classroom creativity (SCC) model proposed by Hong and Song (2020). This model consists of five components: students’ characteristics, participation in science class, science teacher support, science classroom environment, and creative behavior. This model considers the student level rather than the scientist level and both the group and individual levels. This means that SCC considers creativity in science classrooms: creativity expressed by students or groups of students in classrooms encompassing the environments and teachers. An ISP is a type of science class that emphasizes interaction between students from different cultural backgrounds.
and utilizes an online class environment. In light of this, SCC is an appropriate framework to evaluate creativity as a lens with a socio-cultural perspective.

One of the ways of achieving this study aim is to closely analyze students’ creative behavior, because it can often be linked to students’ intercultural experiences, as they draw on diverse perspectives and knowledge to generate new ideas and solutions (Dunne, 2017). Creative behavior has been considered a complex process of idea generation and problem solving that involves individual variation and contextual and social factors (Hong & Song, 2020; Woodman & Schoenfeldt, 1990). There is a need to develop methods for evaluating and assessing creative behavior in a way that acknowledges its complexity and diversity. The use of both quantitative and qualitative data, including surveys, observation, and interviews, can provide insights into the nature and quality of students’ creative behavior in the context of STEAM and science education (Fishkin & Johnson, 1998). The research questions for this study were as follows:

1. What is the impact of the designed intercultural STEAM program high school students’ creativity in the science classroom?
2. How does high school students’ creative behavior manifest in the intercultural STEAM program?

2 Literature Review

2.1 Creativity

Before the 20th century, creativity was considered an individual’s talent, genius, or gift (Becker, 1995). Starting in the 20th century, creativity has come to be regarded as a common ability that everyone has and that can be improved in various contexts (e.g., Guilford, 1950; Torrance, 1965). However, recent studies have no longer regarded creativity as an individual cognitive ability. The expression of creativity has been considered an interaction between various components surrounding individuals and groups or organizations (see Table 1).

Rhodes (1961) proposed the four Ps of creativity: person (individual characteristics), process (the steps involved in the creative process), product (the end result of the creative process), and press (the external factors that influence the creative process). Woodman and Schoenfeldt (1990) proposed an interactionist model of creative behavior that includes person (individual characteristics), consequences (the outcomes of the creative process), situation (the context in which the creative process takes place), behavior (the actions taken during the creative process), and antecedent conditions (the factors that precede the creative process). Siau (1995) proposed a model of group creativity that includes individual characteristics, group characteristics, creative process,
creative climate, and creative products. Sternberg (2012) proposed an investment theory of creativity that includes abilities, knowledge, styles of thinking, personality attributes, motivation, and environment. All of these models focus on different aspects of creativity and the factors that influence it. Some focus on individual characteristics, while others focus on group dynamics or external factors. Nonetheless, all of them are useful for understanding different aspects of creativity.

Unlike past ways of doing science, which developed through the discoveries of a small number of great individual scientists, current ways of doing science have been evolving through collaborative research by various scientists in universities and laboratories (Simonton, 2004; Ziman, 2000). Creativity in science education should also reflect on the characteristics of conducting modern science and the flow of preceding research on creativity. In other words, creativity in science education should be understood not as an individual's cognitive ability, but as the totality of the process and results of collecting creative ideas by students and groups under the influence of the classroom environment.

2.2 Scientific Creativity and Science Classroom Creativity

In previous studies, SCC have been explored as domain-specific types of creativity (e.g., Hu & Adey, 2002; Park, 2004). Based on Rhodes's (1961) four Ps of creativity model, Table 2 provides a summary of the components of the scientific creativity and science classroom creativity models proposed by various authors. By considering individual characteristics, the creative process itself, the final product, and the contextual factors that surround creativity, researchers can gain a more complete understanding of creativity in different domains (Csikszentmihalyi, 1999).
Table 2 Components in scientific creativity and science classroom models

<table>
<thead>
<tr>
<th>Authors</th>
<th>Model</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Park (2004)</td>
<td>Model of scientific creativity</td>
<td>Scientific knowledge content, creative thinking Scientific inquiry skills</td>
</tr>
<tr>
<td>Hong &amp; Song (2020)</td>
<td>Componential model of science classroom creativity</td>
<td>Student characteristics (e.g., scientific knowledge, thinking style) Engagement in science class (e.g., scientific inquiry, expression) Creative behavior (e.g., idea generation, problem solving) Science classroom environment/ science teacher support</td>
</tr>
</tbody>
</table>

2.2.1 Science Creativity
Scientific creativity, or science creativity, means creativity in the domain of science. From the perspective that creativity is domain specific, it is important to understand that creativity can be expressed differently depending on the context (Csikszentmihalyi, 1999). Scientific creativity is related to professional knowledge, and the role of logic is important, unlike in artistic creativity (Lim et al., 2009; Simonton, 2004).

Table 2 presents two models of scientific creativity: Hu and Adey’s (2002) scientific structure creativity model (SSCM) and Park’s (2004) model of scientific creativity. While both models consider individual and process skills,
Park’s model places greater emphasis on factors such as scientific knowledge content, creative thinking, and scientific inquiry skills, while Hu and Adey’s model focuses more specifically on traits such as fluency, flexibility, and originality, as well as the process of imagination and thinking. However, these models may have limitations in that they primarily focus on individual and cognitive aspects of creativity. It is important to consider the role of the science classroom environment and teacher support in fostering creativity in science classrooms, as students may have limited attention spans and excessive professional background knowledge may restrict their thinking range (Park, 2004). Therefore, it is essential to take into account students’ individual levels of creativity (Cho, 2012; Kaufman & Beghetto, 2009) and provide a supportive environment that encourages creativity.

2.2.2 Science Classroom Creativity
Unlike other scientific creativity models, the SCC model developed by Hong and Song (2020) considered student level. In addition, the SCC model includes components of leadership (the support of science teachers) and press (the science classroom environment; see Table 2 and Figure 1). This is a sociocultural approach to science education that can be achieved through teacher-student interaction and student-student interaction in the science classroom environment. This approach emphasizes contextual perspectives and focuses on new and valuable ideas and behaviors that appear in the process of individuals interacting with groups and societies (Amabile, 1988; Csikszentmihalyi, 1999; Plucker & Beghetto, 2004; Sawyer, 2011). Therefore, the science classroom creativity model can specifically provide guidelines on what creativity could be pursued in science classrooms.

Figure 1 depicts the SCC model (Hong & Song, 2020), a framework that is aimed at understanding the factors that contribute to scientific creativity in the classroom. The model is organized into two primary categories: internal and external components.

Internal components of the SCC model focus on the personal attributes of students that can affect their scientific creativity. These components include characteristics such as scientific knowledge, thinking style, intrinsic motivation, interest, participation in science class, and creative behavior. These factors are internal to the individual student and relate to their own personal characteristics and actions. External components, on the other hand, relate to the social and environmental factors that surround the student in the science classroom. These components include the support of science teachers and the environment of the science class. Science teachers can provide support...
for creativity by encouraging students, providing resources, and creating a positive classroom environment. The science classroom environment can also influence creativity by offering opportunities for exploration, experimentation, and collaboration.

The SCC model emphasizes the importance of considering both internal and external factors when understanding students’ scientific creativity. This model recognizes that creativity is not solely an individual trait but is also influenced by social and environmental factors. By considering these factors, teachers can create a classroom environment that fosters scientific creativity and supports their students in their pursuit of new and valuable ideas.
3 Method

3.1 Research Design

The research procedure is shown in Figure 2. First, a literature review was conducted to analyze which topics and elements were appropriate for the ISP. The program was then developed by two STEAM education experts, including the primary researcher, and was reviewed by three secondary science teachers (two from Korea and one from Australia). Finally, the program, which consisted of eight class hours, was piloted with 10th-grade high school students in science classrooms in Australia and Korea.

A sequential explanatory mixed-methods design was employed to address the study’s research questions (Creswell, 2014). In this design, quantitative data and qualitative data are collected and analyzed in sequence. This method integrates two types of data to help view the research problem from different perspectives (Creswell, 2014).

3.2 Participants

The study recruited participants from high-ranking public schools in two geographical regions: Korea and Australia. The lessons were delivered to 25 first-year (10th-grade) students at S High School in Gyeonggi-do, Korea, and 25 10th-grade students at H High School in Sydney, Australia. However, due to COVID-19 issues, while Korean students participated in full classes and were observed by researchers, Australian students were only able to participate
in certain parts of the classes. Although schools in Sydney were conducting face-to-face classes during the data collection period, researchers were not permitted to visit the school to observe small-group science activities and discussions between November 20 and December 29, 2021. As a result, data could only be gathered from the Korean students, but the study was able to collect survey data from 25 students and interview data from 10 students in this group. However, the lack of data from the Australian students remains a limitation of the study.

3.3 Development and Implementation of the Intercultural STEAM Program

3.3.1 Intercultural STEAM Program Topic: Designing a Zero-Energy House

The program topic chosen was the global issue of energy, specifically, designing a zero-energy house. An analysis of curricula in Korea and Australia showed that this topic combined various science concepts such as heat, energy transfer, conduction, convection, and various types of energy. Because these concepts are covered throughout the 6th to 10th grades in both Korea and Australia, the participating students could be assumed to have some prior knowledge of the topic. This topic also allowed students to make use of their creative ideas on how to learn science and form new science concepts that could arise from their cultural and geographical differences.

3.3.2 Development and Implementation of the Program

The program, including its unit schedule and worksheets, was developed in accordance with the context, creative design, and emotional touch criteria for STEAM presented by the Korea Foundation for the Advancement of Science and Creativity (KOFAC) (Kim et al., 2019). The program for designing a zero-energy house was developed by a high school teacher, working in collaboration with the ISP researchers, who was in a PhD study program on science education and was also a STEAM expert. The draft was reviewed by two STEAM experts. The Korean high school science teacher and two Australian high school science teachers who would be teaching the newly developed program together reviewed the validity, composition, and content of the series of lessons. After three feedback sessions, modifications, and supplementations, the final program was completed. The program was conducted in simultaneous and non-simultaneous interactive forms using online platforms and online meetings on platforms such as Zoom, Google Classroom, and Padlet (see Figure 3). The online class environment had the flexibility to allow students to participate in classes regardless of time and space (Daymont & Blau, 2008; Davis et al., 2019).

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The program, which focuses on intercultural interactions, was based on the 5E instructional model for STEAM programs developed by Chu et al. (2019), which emphasizes the co-constructivist approach to learning. This approach recognizes that knowledge is socially and culturally constructed, leading to multiple perspectives on the same issue. The 5E model promotes the development of important skills, such as collaboration, communication, and creativity through group activities and discussion (Bybee et al., 2006). Therefore, through 5E, students can have opportunities to construct explanations and apply their knowledge to real-world problems and think creatively (Bybee et al., 2006). Using the 5E model also allowed for an emphasis on interaction and cooperation, which are key aspects of the ISP. The specifics of instructional strategies for designing a zero-energy house are presented in Table 3.
Table 3  Development of intercultural STEAM program on designing a zero-energy house

<table>
<thead>
<tr>
<th>STEAM criteria</th>
<th>5E</th>
<th>Learning content</th>
<th>Intercultural component</th>
<th>Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Situation presentation</td>
<td>Engage</td>
<td>Introduction to zero-energy house design challenge</td>
<td>Introducing global interests of science problems (Designing zero-energy house)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Zoom</td>
</tr>
<tr>
<td>Creative design</td>
<td>Explore</td>
<td>Developing science conceptual understanding</td>
<td>Sun's altitude changes throughout the year in the southern hemisphere/northern hemisphere. How does this influence people's cultural practices?</td>
<td>2–3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) daylighting design: solar geometry.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) water storage container design: energy transfer</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(insulation and conduction).</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Explain</td>
<td>Intercultural group activity: Exchange of cultures (architecture, climate, etc.) between Korea and Australia</td>
<td>Why do Korean houses face north and Australian houses face south?</td>
<td>4–5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Zoom</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Kor-Aus cooperative class)</td>
</tr>
<tr>
<td></td>
<td>Elaborate</td>
<td>Design challenge</td>
<td>Designing a creative zero-energy school for each other</td>
<td>6–7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Zoom</td>
</tr>
<tr>
<td></td>
<td>Evaluate</td>
<td>Intercultural group activity: Final presentation: exchange feedback</td>
<td>Sharing on the digital platform with Australian students</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Zoom, Padlet</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Kor-Aus cooperative class)</td>
</tr>
</tbody>
</table>

Note: During intercultural group activity, Korean students and Australia students had a face-to-face meeting through zoom.
The zero-energy house design in Table 3 is described in detail as follows. At the engage stage, the Korean students were intrigued by the global interests of science problems (e.g., zero-energy house design), even if they were in different cultures. At the explore stage, Korean students carried out hands-on activities and learned the science concepts (e.g., solar geometry and energy transfer) and asked how they could apply it to other cultures (e.g., where will the sun rise and fall in the Southern Hemisphere?). At the explain stage, six groups were formed, each with a mixture of Korean and Australian students, who then explained and shared their own cultures, architecture, and climates.

Most of the Korean students introduced the *hanok*, which is a type of Korean traditional architecture, while most of the Australian students described their hot climate and house structure in Sydney. Students were able to ask questions about different residential and climate cultures (e.g., why do Korean people like houses facing south or south-east and Australian people like houses facing north or north-east?). At the elaborate stage, the Australian students played the role of clients asking the Korean students to become architects and design school buildings. Role-switching was a key factor in this stage: The Korean students requested that the Australian students design a warm school building because of Korea’s cold winter weather, whereas the Australian students wanted their Korean counterparts to design a school building with a swimming pool due to their hot weather. After this, each group performed the zero-energy house design challenge. These activities contributed to the growth of students by relating science to culture and cultural traditions (NESA, 2018). At the evaluate stage, students in each country presented their designs via Zoom and reviewed and gave feedback about each other’s artifacts via the Padlet online discussion platform.

Most Korean and Australian teachers conducted their own classes during module 1–8. However, in the explain stage (module 4–5), Korean and Australian students had a face-to-face meeting through zoom in simultaneous time and conducted intercultural activities. In the evaluation stage (module 8), non-simultaneous time intercultural activities with Australian students were conducted through Padlet.

### 3.4 Revised Science Classroom Creativity Questionnaire and Interview Questions

To answer Research Question 1, “What is the impact of the intercultural STEAM Program on high school students’ creativity in science classrooms?” the science classroom creativity questionnaire (SCCQ) (Hong et al., 2022) was modified. The SCCQ was developed for investigating students’ scientific creativity in the science classroom context from an integrative point of view, taking into
account the student’s interaction with the surrounding social environment and with the teacher and thus identifying creativity from a sociocultural perspective. For example, the SCCQ includes items on the influence of science teacher support and science classroom environment and the characteristics of students and their creative behavior.

To measure students’ learning experience when using different curricula and in different classroom cultures and races in different countries (Australia and Korea in our study), we added some items (see Table 4) to the SCCQ based on other studies (e.g., Chi & Ju, 2012; Park et al., 2019). The revised questionnaire was named the Revised-Science Classroom Creativity Questionnaire (R-SCCQ) in this study. However, due to the prolonged COVID-19 situation, data from Australian students could not be collected, making comparisons between the countries impossible.

3.4.1 Pilot Test

The pilot test of the R-SCCQ was trialed with 15 high school students. A 5-point Likert scale with the responses strongly agree, agree, neutral, disagree, and strongly disagree was used for this process. The results showed that the students tended to choose the moderate option of neutral. Thus, based on several studies (e.g., Brown, 2000; Lozano et al., 2008) the questionnaire was revised to a 4-point Likert scale of strongly agree, agree, disagree, and strongly disagree to identify the trend of students’ responses more clearly.

<table>
<thead>
<tr>
<th>Section</th>
<th>Item no.</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students’ science learning experience</td>
<td>31</td>
<td>I read books and magazines related to science.</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>I watch TV shows (documentaries, etc.) related to science.</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>I watch movies and dramas related to science.</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>I look up scientific information on the internet (YouTube, etc.).</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>I use a computer or smartphone app to do science-related activities.</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>I go to a science museum or observatory.</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>I fix or make things (woodworking, Lego toys, blocks, knitting, embroidery, science boxes, electronic kits, Arduino, 3D printers, etc.)</td>
</tr>
</tbody>
</table>
In addition, the questions that students reported not understanding well or that they felt overlapped were reviewed and corrected with two other researchers. For example, students said that the questions “I have solved a problem in a new way in science classes” (individual creative behavior) and “My class/group has solved a problem in a new way in science classes” (collective creative behavior) were not distinguished so it was difficult to respond to those items. This may be due to the thinking style of many Korean students, who tend to consider “I” and “we” the same and tend not to distinguish them (Nisbett, 2004). Therefore, considering that the SCCQ is a self-reporting measurement, the questionnaire was revised to focus on the individual creative behavior.

3.4.2 Finalized Questionnaire

This study revised the 49 items of SCCQ to create the 55 items of the revised SCCQ (R-SCCQ) after a pilot test and several reviews by researchers (see Table 5). The R-SCCQ consisted of five dimensions: students’ characteristics, participation in science class, science teacher support, science classroom environment, and creative behavior (see Table 6).

| TABLE 5 | Comparison of the Science Classroom Creativity Questionnaire (SCCQ) and the Revised-Science Classroom Creativity Questionnaire (R-SCCQ) |
|--------------------------|---------------------------------------------------------------------------------|--------------------------|
| **SCCQ (number of items)** | **R-SCCQ (number of items)** | **Revision made** |
| Student characteristics (9) | Student characteristics (21) | Added items of “students’ science learning experience” |
| Participation in science class (10) | Participation in science class (10) | |
| Science teacher support (12) | Science teacher support (9) | Revised items of “emotional support of science teacher” |
| Science classroom environment (9) | Science classroom environment (9) | |
| Creative behavior (9) | Creative behavior (6) | Revised items of “collective creative behavior” |
| 49 items | 55 items | |
| 5-point Likert scale | 4-point Likert scale | |
The reliability of the R-SCCQ was estimated using Cronbach’s α. The result of the Cronbach’s α test was above .7 (see Table 6) in all dimensions. This level of reliability is acceptable in questionnaire research (Nunnally & Bernstein, 1994).

### 3.4.3 Interview Questions

We also developed interview questions for students about creative behavior to examine it more deeply after conducting a pre- and post-test of R-SCCQ. Dunne (2017) suggested two ways to discuss the relationship between creativity and
intercultural experience: the generative process, involving producing, accessing, and combining ideas, and the exploration process, involving further examining and evaluating emergent ideas. Hong and Song (2020) also presented the components of creative behavior as “idea generation” and “problem-solving.” Therefore, in this study, interview questions were developed in two categories to analyze creative behavior: (1) the generative process, in other words what the source of students’ inspiration and conceived ideas was, and (2) the exploration process, in other words, how the students examined the various ideas to make a final decision (see Table 7).

3.5 Data Collection
We collected data using the R-SCCQ, made classroom observations through video recordings, collected student outcomes, and conducted semi-structured interviews.

3.5.1 Questionnaire
The R-SCCQ was distributed to 27 students before and after the program and took about 20 minutes. However, two students did not complete the questionnaire, so the actual number of students whose questionnaire data were used for the analysis was 25.

3.5.2 Classroom Observation
During the eighth classes, the researchers observed and recorded the whole of the class through Zoom; however, during the explore stage, hands-on activities were recorded using video recorders.
3.5.3 Students’ Activity Outcomes
The activity outcomes of the students were also collected through Google Classroom and Padlet. PowerPoint slides or scripts that students produced for intercultural activities were collected. The students’ final zero-energy house designs were collected as well.

3.5.4 Interview
After completion of the whole program, in-depth interviews were conducted via Zoom with 10 students recommended by the teacher. The average interview time was 50 minutes. The interview questions were aimed at uncovering specific examples of the expression of creativity in science classes, focusing especially on creative behavior, which was considered difficult to observe through the questionnaire alone. Questions were also asked about the online class environment and international cultural exchange activities, which were both characteristic of the ISP. Interviews were semi-structured to allow students to answer by expressing their thoughts openly. The video recordings and interviews were all transcribed using the Happy Scribe online transcription program.

3.6 Data Analysis
This study used a mixed research method with sequential explanatory design to collect and analyze quantitative and qualitative data one after another and then synthesized them to form conclusions (see Table 8).

<table>
<thead>
<tr>
<th>Type</th>
<th>Method</th>
<th>Sample</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantitative data</td>
<td>Questionnaire (55 questions)</td>
<td>25 Korean students</td>
<td>Descriptive and paired-sample t-test statistical analyses using SPSS ver. 24</td>
</tr>
<tr>
<td>Qualitative data</td>
<td>Semi-structured interview</td>
<td>10 Korean students</td>
<td>Three coding steps (in vivo coding, SSC coding, review coding) using transcription and identified themes by researchers using NVivo 12 plus</td>
</tr>
<tr>
<td></td>
<td>Classroom observations</td>
<td>27 Korean students</td>
<td></td>
</tr>
<tr>
<td></td>
<td>with video recordings and students’ activity outcomes</td>
<td></td>
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</tbody>
</table>
3.6.1 Analysis of Quantitative Data
For the quantitative data, a paired-sample t-test was performed using SPSS (version 24) to determine whether there was a significant difference between the pre- and post-tests. The questions on the 4-point Likert scale were given 4 points for strongly agree, 3 points for agree, 2 points for disagree and 1 point for strongly disagree. The mean and standard deviations were expressed up to the second decimal place. At the level of significance $p < .05$, the difference between pre- and post-tests was verified and determined. The statistical findings were used for radar and spider charts to visualize data.

3.6.2 Analysis of Qualitative Data
The interviews and class observations and students’ activity outcomes were all collected in linguistic form, so they were classified as qualitative data, and the researchers worked on interpreting the implied meanings of these materials. An iterative comparative analysis method was performed, using NVivo 12.

**FIGURE 4** An example of interview data analysis through three coding steps

As shown in the figure, the recorded interviews were classified into SCC components along with the pertinent codes. The recorded interviews are: "The height of the sun varies from season to season. I thought about why I was learning that, especially when I was in middle school, but I never imagined that I would think about lighting when I was building an apartment or a house based on that, and I didn’t even know why a south-facing house was expensive and good, but I think this time I did a lightning experiment, and I got a clear idea of why a south-facing house is expensive.”

The recorded interviews were highlighted and in vivo coding was performed:

- Knowing with certainty “the altitude of the sun according to the seasons.”
- Learning why I should learn scientific concepts.
- Being able to imagine things I had never before imagined.
- Getting to know through experimental activities.
- Gaining a clear understanding of scientific concepts.

Finally, the codes and categorizations were confirmed.
Plus software to make it easier to construct a code hierarchy and to collaborate with other researchers than it would have been with a more manual approach (Yin, 2015).

The researcher analyzed the qualitative data through three coding steps (see Figure 4). In the first step, researchers carefully read all qualitative data, highlighting what they thought was important. Alternatively, codes were formulated by reusing the words or phrases that the students used during their interviews. This coding method is called in vivo coding, and it has the advantage of being able to vividly reveal the thoughts of the participants (Yin, 2015). In the second step, a categorization task was performed using the SCC components. Step 3 was a repeat of Step 2: About a month after the end of Step 2, the researcher repeated the categorization based on the original data and the first coding. This coding was reviewed by one science education expert and the final categories were determined.

4 Results

What was the impact of the ISP on the science classroom creativity of high school students? How did high school students’ creative behavior manifest in the intercultural STEAM program? In this section, we show findings from several data sources.

4.1 The Impact of the Intercultural STEAM Program on Creativity in the Science Classroom

The findings from a paired sample t-test are provided in Table 9.

The results showed a significant increase in the dimensions of student characteristics \((p = .001)\), participation in science class \((p = .010)\), science class environment \((p = .011)\), and support of science teachers \((p = .008)\). However, there was no significant increase in the dimension of creative behavior \((p = .111)\). This indicates that the ISP developed and implemented in this study had a positive effect on science classroom creativity, except for the creative behavior dimension. Therefore, it was mandatory to supplement the interpretation of quantitative results by analyzing qualitative data.

The differences between post- and pre-test scores for students who had taken the intercultural STEAM program were \(+0.222\) in the student characteristics dimension, \(+0.212\) in the participation in science class dimension, \(+0.227\) in the science teacher support dimension, and \(+0.209\) in the science classroom environment dimension. In the creative behavior dimension, although the
### Table 9: Pre- and post-t-test comparison in Revised-Science Classroom Creativity Questionnaire (R-SCCQ) (N = 25)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Pre</th>
<th>Post</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Student characteristics</strong></td>
<td></td>
<td></td>
<td>2.831</td>
<td>0.451</td>
<td>−3.924</td>
<td>.001**</td>
</tr>
<tr>
<td><strong>Participation in science class</strong></td>
<td></td>
<td></td>
<td>2.980</td>
<td>0.479</td>
<td>−2.789</td>
<td>.010*</td>
</tr>
<tr>
<td><strong>Science teacher support</strong></td>
<td></td>
<td></td>
<td>3.151</td>
<td>0.479</td>
<td>−2.910</td>
<td>.008**</td>
</tr>
<tr>
<td><strong>Science classroom environment</strong></td>
<td></td>
<td></td>
<td>3.071</td>
<td>0.486</td>
<td>−2.749</td>
<td>.011*</td>
</tr>
<tr>
<td><strong>Creative behavior</strong></td>
<td></td>
<td></td>
<td>2.933</td>
<td>0.414</td>
<td>−1.66</td>
<td>.111</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01.

**Figure 5** Visualisation of students' group creativity development in five dimensions.
difference of +0.107 was not statistically significant, it is important to note that it was still a positive value. This suggests that participating in the intercultural STEAM program may have had a positive impact on students’ ability to generate new ideas and explore decision-making processes, as perceived by the students themselves. These findings are consistent with the overall positive impact of the program on science classroom creativity, as shown in Figure 5.

4.2 Manifestation of Creative Behaviors

There was no significant quantitative change in the creative behavior dimension of the R-SCCQ responses before and after the ISP, even though the post-test score was higher than the pre-test score. To gain a better understanding of this finding, the researchers extracted specific examples through various types of qualitative data (e.g., in-depth interviews and outcomes from students’ activities). From this, we aimed to identify the characteristics of the creative behavior that were not identified in the quantitative data.

To closely examine creative behavior, this study narrowed its focus to two categories based on previous research (Dune, 2017; Hong & Song, 2020): (1) generative process and (2) exploration process. The result of this analysis of creative behavior is summarized and shown in Figure 6.

4.2.1 Generative Process: What Was the Source of Students’ Inspiration and Conceived Ideas?

To analyze the sources of the ideas expressed in designing a zero-energy house, the analysis was conducted mainly based on the recording transcription data of the last class (eighth session) and the in-depth interview transcription data. This resulted in the data falling into three categories: intercultural

Figure 6 Manifestation of creative behavior through the ISP
activities with Australian students, research activity, and knowledge learned in science class.

4.2.1 Intercultural Activities with Australian Students
Group 1 discovered that a tall roof is a feature of houses in Australia when they saw pictures of these houses in the intercultural activity session with Australian students. From this, they also came to better understand the scientific knowledge of convection. Group 1 was inspired by this and so presented its design of the zero-energy house with a high roof to maintain temperature.

G1-A: My Australian friends showed me their house, and they said that one of the features of the house is a high roof. ... From what my friends said, if the roof itself is high, the hot air can go out quickly, so the indoors can be cool in summer.

Interview

Student G4-A was impressed by the wide grass field at the Australian school when the Australian students showed it to him. Student G4-A initially thought that the reason for using grass on the football field was for players to be less injured than they might be on sand when someone fell. However, upon further investigation of the grass, he discovered that it could also reduce the temperature of the atmosphere through air purification and transpiration. He then reflected this grass field idea in his group design of the zero-energy house (see Figure 7).

![Figure 7 Zero-energy house design outcome by Group 4](image-url)
G4-A: I thought our school in Korea had good facilities, but from what Australian friends showed me, ... the classrooms were very spacious and outdoors lawn was very good compared to my school in Korea. When I had more interactions with Australian students via Zoom and online platforms, I was able to learn a lot of good information about the efficient role of natural grass, so I put it in [our design].

Interview

Student G6-A said that he researched the hanok for intercultural activities with Australian students and obtained some ideas in the process. He said he learned that the hanok structure in the colder northern part of Korea is a square shape but is a straight or L-shape in the warmer southern part. Therefore, since Australia has a hotter climate than Korea, he applied an L-shape structure in his design for the zero-energy house (see Figure 8).

G6-A: During our intercultural activities with Australia, we investigated and presented the structure of the hanok, which is L-shaped in the southern part of Korea to make it airy. I fell in love with that idea, so I talked to my friends, and we reflected that idea in our design.

Interview

4.2.1.2 Research Activity

Student G1-A used the Street View feature of Google Maps to see the topography and the appearance of Australia. He searched for not only text material but
also photographic material and even vivid media resources such as YouTube. Through this, he said he was able to come up with ideas about the layout and shape of the house.

G1-A: Since this project was to design a school building scientifically as a passive house, I looked up videos and photographs because I thought the text information was not enough to investigate the exterior or location of the Australian houses and whether they faced south or north.

Interview

4.2.1.3 Knowledge Learned in Science Class
Student G3-A said he got his idea from the hands-on activities conducted during the second and third sessions of the ISP. He responded that experiments had helped him to acquire exact and detailed knowledge of science, which he could not have obtained simply by reading books. Student G1-A came up with the idea of vacuum insulation material by applying the knowledge of heat transfer from information presented by another group in the science class rather than what was presented in the ISP. From this, the researchers found that the students had learned scientific knowledge through the science class and had generated ideas based on this.

G1-A: For the exterior walls of the school, we first used vacuum insulation material for effective insulation ... Once another group presented about the thermos in science class. That’s the same principle. Vacuum insulation material is the same principle as a thermos.

Classroom observation

The findings suggest that students learned scientific concepts through hands-on activities and experiments during science classes. These learned concepts were then applied when generating ideas to solve problems related to passive energy school design for Australian students. Students actively generated ideas because they had to solve problems in a new context (e.g., Australia). As Student G6-B mentioned during an interview, they might not have been as excited to solve passive school issues in Korea as they had been to solve them for the Australian context. The study highlights the importance of intercultural activities, such as the ISP, as a teaching and learning strategy to promote students’ science classroom creativity.

Researcher: What do you think the class would have been like without intercultural activities?
G6-B: If we had had to build a house in our own country instead of Australia, it might have been less exciting because we were already familiar with our residential culture. Building a house in Australia was a new and challenging project, and it allowed us to examine everything from the beginning about what the building should be.

Interview

4.2.2 Exploration Process: How Did Students Examine the Various Ideas to Make a Final Decision?

We interviewed the students about how they decided on their final ideas and their processes of determining ideas. Students who were in a cooperative atmosphere recognized that they had created creative ideas, while those who did not collaborate expressed regret in their output. In addition, we explored the characteristics of the process of determining students’ creative ideas (reverse thinking).

4.2.2.1 Process of Determining Ideas

The groups decided on their final solutions in various ways. However, the groups were observed to share a common process of determining ideas: collect ideas, evaluate ideas, and further examine ideas. This is consistent with the results of Dunne (2017). This process was described in detail through the in-depth interviews (see Table 10).

As shown in Table 10, Group 3 collected ideas and came up with the idea of double-glazed windows for a napping room that Australia students asked for during intercultural activities. They also further examined the idea and found that soundproofing was another function it could serve. The group evaluated the idea positively because it can work toward meeting the needs of Australian students while also increasing energy efficiency. This was an excellent example of science classroom creativity.

In Group 6, all the members actively communicated. They collected the idea “Let’s dig a tunnel in the basement and build a house.” This idea came from an intercultural activity with Australian students. They introduced the idea to Korean students that traditional indigenous homes in Australia in ancient times were built by digging a cave under a cliff to escape the sun. Group 6 thought the cave dwellings were a very interesting and original idea, so they tried to apply it to their design. However, some students evaluated the idea and opposed it. A house built by digging a cave does not receive light, so some said it is “not comfortable” even if it is cool in summer. After a long and logical discussion, Group 6 discarded the idea of building a cave house.
In Group 5, however, roles were divided up and distributed without discussion and then the members simply combined the individually designed sections to produce the final outcome (see Figure 9). Student G5-A expressed regret that they could have produced a better design through communication with more members.

G5-A: First, we cut the school into pieces and divided the design up without talking. ... I just wanted to finish it quickly, but if we had done it after a lot of discussions, we could have come up with more ideas from the beginning about what to consider or what the environmental factors were.

Interview

An analysis of the interviews showed that the groups followed a common process of determining ideas that included collecting, evaluating, and further examining. However, special processes that appear because of ISP were also observed. When collecting ideas, students came up with ideas more diversely
due to the influence of Australian students and made decisions through active communication. The intercultural activities and active communication played a key role in brainstorming and coming up with divergent scientific ideas.

4.2.2.2  *Reverse Thinking*

We found that in the process of collecting, evaluating, and further investigating various ideas, students reversed their ideas to come up with more creative ideas. An example was found in an interview with G3-B. He had learned about a house built off the ground through intercultural activities. However, the student's group did not use this idea in their design. Instead, they applied the opposite concept of using heat transferred from the ground for heating, which is an example of reverse thinking. This approach can lead to very original ideas, even at a student's level.

G3-B: Traditional houses in both Australia and Korea were designed to be off the ground to avoid heat transferred from the ground. So, we decided to just use the heat in reverse. Rather, we designed the house to contact the ground to use the heat from ground.

*Interview*

We were able to find a similar case in Group 1. In Group 1, Student G1-A participated in the program most actively. However, he said there had been a
“collision” between the opinions of group members when considering the thoughts of both the Australian and the Korean students at the same time. It was a clash between opinions that houses should be designed to be warm in winter and cool in summer.

G1-A: There were many opinions from Australian and Korean students at once, so there were overlapping and conflicting things. It was hard to arrange. For example, it must be well ventilated, of course, it must be well insulated, and we kept on thinking about which one would have better thermal efficiency.

Interview

When these conflicting opinions occurred, students held their own discussions on which opinions were better. Student G1-A explained that he had a reverse idea in this process. He came up with the idea that with perfect insulation, it would be warm in winter and cool in summer. He explained the idea to the group members, and after a long discussion, Group 1 finally concluded that the house would be designed in a way that provided perfect insulation. G1-A: I think that we could have generated better ideas by thinking about it in reverse.

Interview

The examples from Groups 3 and 1 show that the process of reverse thinking could lead to more creative and original ideas. The students had conflicting opinions but held discussions to evaluate and investigate various ideas, which eventually led to the application of reverse thinking. The outcome was more creative and efficient solutions for designing the house. Therefore, it can be argued that reverse thinking is a valuable approach in generating new and original ideas.

5 Conclusion

This study developed an intercultural STEAM program (ISP) and applied it to Korean and Australian high school students. The researchers used the R-SCCQ to investigate the impact of the ISP on students’ creativity in science classrooms but were only able to investigate this in Korean science classrooms because data collection in Australia was not possible owing to COVID-19 pandemic restrictions. The study also explored the characteristics of the Korean high school students’ creative behavior manifested during the intercultural
STEAM program. Various types of qualitative data (interviews, classroom observation, and student outcomes) were collected and analyzed to address the research questions. The conclusions drawn from the results are as follows:

First, the ISP in practice had a positive effect on students’ science classroom creativity. The R-SCCQ responses showed that the students’ performance in the four dimensions of science classroom creativity improved significantly, but the significant changes in the dimension of creative behavior could not be investigated using either Likert-scale items or in the R-SCCQ. However, qualitative data analysis, including interviews, showed that the students did indeed manifest creative behavior in their science classes. The analysis of both quantitative and qualitative data in this study shows that the ISP positively affected students’ creativity in science classrooms.

Second, intercultural experiences played a crucial role in fostering science classroom creativity. This study revealed through interview data that the main source of ideas for the Korean students was the intercultural activities with Australian students. Korean students came up with more ideas and were motivated to conduct further research after intercultural activities. This study also found that the zero-energy house designed by Korean students for Australian students reflected this creativity, as the students utilized scientific concepts to enhance energy efficiency. They showed unique ideas such as an L-shaped school and a grass field. That is a testament to the benefits of intercultural experiences. This study provides empirical evidence to support the claims of several previous studies (e.g., Chao et al., 2015) that intercultural experience exposes students to a variety of perspectives and induces flexible and fluent ways of thinking. The use of the ISP may therefore have contributed to their innovative approach.

Third, science classroom creativity, especially creative behavior, should be evaluated through various methods. In this study, the results of investigating the creative behavior dimension that were obtained using the R-SCCQ were not significant. The response figures in the creative behavior dimension were smaller than those in other dimensions, similar to the results of previous studies (e.g., Hong et al., 2022). However, through qualitative data, it was possible to conclude that the students’ creative behavior had also clearly been enhanced (Fishkin & Johnson, 1998). The researchers identified two categories of creative behavior, the generative process and exploration process, and used specific examples from in-depth interviews and outcomes from student activities to understand the manifestation of creative behaviors. Finally, the researchers supplemented the quantitative data with qualitative data to gain a better understanding of the creative behavior dimension. The R-SCCQ, however, may not be sufficient to measure creativity and creative behavior in students, as it relies on students’ own judgments. This shows the need to improve the
questions in the R-SCCQ or develop additional measuring tools such as observation or interviews.

This study explored the impacts of an intercultural STEAM program on high school students’ creativity in the science classroom. We suggest that this ISP can be a good teaching strategy to enhance creativity. ISP can take place across the boundaries between countries with IT technology development such as recent education system like MOOCs and Minerva University (Ahalt & Fecho, 2015). Students from various backgrounds can learn together and carry out projects online. In the field of science education, research on the development of various class topics that include intercultural activities and exploration of their effectiveness is required. The ISP developed in this study can be taken as an example of this.

It is necessary to collect and analyze the Australian students’ data. Currently, the ISP project team is working on Australian data collection and analysis. In the future, it will be necessary to analyze the effect of the ISP by collecting student creativity data from many classes across various countries to explore the generalized patterns arising.

**Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ISP</td>
<td>Intercultural STEAM Program</td>
</tr>
<tr>
<td>R-SCCQ</td>
<td>Revised Science Classroom Creativity Questionnaire</td>
</tr>
<tr>
<td>SSCQ</td>
<td>Science Classroom Creativity Questionnaire</td>
</tr>
<tr>
<td>STEAM</td>
<td>Science, Technology, Engineering, Art, Mathematics</td>
</tr>
</tbody>
</table>

**Acknowledgements**

We wish to express our gratitude to the students who participated in this study as well as the colleagues who supported it. We also thank Hyeong Moon Lee for his collaboration on developing intercultural STEAM classroom program for this research. Finally, we would like to thank the anonymous reviewers for their helpful suggestions and feedback.

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Ethical Considerations

The data collected from this project has obtained the necessary clearance from the school(s), guardian(s) and the students involved in the study.

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