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Exploration of Korean Students' Scientific Imagination Using the Scientific Imagination Inventory

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This article reports on the study of the components of scientific imagination and describes the scales used to measure scientific imagination in Korean elementary and secondary students. In this study, we developed an inventory, which we call the Scientific Imagination Inventory (SII), in order to examine aspects of scientific imagination. We identified three conceptual components of scientific imagination, which were composed of (1) scientific sensitivity, (2) scientific creativity, and (3) scientific productivity. We administered SII to 662 students (4th–8th grades) and confirmed validity and reliability using exploratory factor analysis and Cronbach α coefficient. The characteristics of Korean elementary and secondary students' overall scientific imagination and difference across gender and grade level are discussed in the results section.

Keywords: *Scientific imagination; Science and imagination; Measurement scale*

Introduction

This study aimed to clarify aspects of scientific imagination and to report the scientific imagination of Korean students. For several decades, researchers have discussed the characteristics and role of imagination. In the field of science, imagination is regarded as an important ability for scientists. Scientists approach and solve problems using imagination and creativity (McComas & Almazroa, 1998). For example, when scientists develop new theories, they visualize scientific phenomena, imagine virtual situations, and construct plausible explanations. Many successful scientists, including Albert Einstein, have described imagination as crucial when accounting for their discoveries. Imagination drove great scientific inventions and discoveries according to survey research on the role of imagination in successful scientists' most famous

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breakthroughs (Shepard, 1988). Likewise, science requires imagination and it underlies epiphanies.

The goal of science education has changed from an emphasis on rationality and logical thinking by understanding scientific content knowledge toward enhancing scientific literacy for living in the twenty-first century as a global citizen (Bybee & McCrae, 2011; Choi, Lee, Shin, Kim, & Krajcik, 2011; Laugksch, 2000; Miller, 1998). Students face complex problems in their everyday life which are related to science such as using new technological instruments, climate change, and genetically modified organism (GMO) products. These kinds of issues require not only scientific knowledge but also the utilization of imagination, creativity, and high-order problem-solving skills. Science educators and philosophers of science support the view of science as a value-laden human activity (Edge, 1985; Frazer & Kornhauser, 1986; Fuller, 1997; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Therefore, it has been argued that imagination and creativity should be emphasized as important outcomes of science education (Kind & Kind, 2007). Recent interviews with distinguished scientists also showed that scientists come up with new scientific questions using their imaginations and they also develop research procedures using imagination (Mun, Mun, & Kim, 2013).

The premise of this research is that it is necessary to recognize the value of imagination in science education. Imagination enables students to enjoy learning and to learn to re-evaluate and meaningfully reconstruct what has been learnt (Egan, 1992). It is also important in the process of memorizing, and enables pupils to think freely by providing flexibility, power, and vitality to human reasoning (Egan, 1992; Warnock, 1976). In the contemporary view, imagination was regarded as a necessary element in human mental activity and also as a source of creativity. Many scholars consider imagination necessary in education (Egan, 1992; Nadaner, 1988; Warnock, 1976) and have long discussed its educational value (Holton, 1998; Kind & Kind, 2007; Mathewson, 1999; Ren, Li, Zhang, & Wang, 2012).

Now we have a question. What are the rules and the characteristics of imagination in science learning? Among scientific activities, thought experiments and modeling activities involve imagination and play an important role in science (Mathewson, 1999). Reiner and Gilbert (2000) argued that imagination in the form of thought experiments can be conducted in science education. Thus, the imagination is involved in the activities of scientists as well as in students' science learning and is closely related to both. Despite scientific activities being dependent on imagination and scientists having active imaginations, imagination has been neglected in practical science education (Gajdamaschko, 2005; Porter & Brophy, 1988), with little discussion of its potential applicability. In contrast, education in drawing and writing using imagination, based on the imaginations of artists and novelists, has been researched extensively (Jiryung & Margot, 2006).

The National Science Curriculum of Korea revised in 2009 emphasizes education that stimulates creativity and imagination. One of the goals of the National Science Curriculum is cultivating people who can solve problems with creativity and imagination; hence, science educators emphasize integrated learning and drive education based on value and character. According to the Korean National Elementary Curriculum revised in 2009, one of the goals is 'to promote students' problem solving skills in life and to develop their imagination' (The Ministry of Education, Science, and Technology, 2012, p. 7). Most Korean schools hold yearly programs and contests to encourage imagination in students, such as imagination drawing or imagination writing in the science context. Recently, science learning integrated with arts has become wide spread in Korea. STEAM (STEM with arts) education based on this movement has played a core role in science education in Korea, which will affect students' imaginations and increase interest and motivation for science learning. Therefore, exploring the characteristics and measuring the imagination of Korean students will identify the importance and effects of imagination on teaching and learning science.

Thus, imagination is one of the important factors we should consider when thinking about science education. For example, the scientific inquiry process, which is one of the important aspects of science, is related to imagination. Wong and Hodson (2009) and Osborne, Collins, Ratcliffe, Millar, and Duschl (2003) investigated the perceptions of actual scientists on imagination and the results showed that imagination is recognized as an important factor in actual scientific inquiry. Especially, scientists claimed that the role of imagination can be differed in every inquiry process. Therefore, it has been argued that imagination should be regarded as a key factor for scientific inquiry (Barrow, 2010; Gilbert, 2004; Hadzigeorgiou, Fokialis, & Kabouropoulou, 2012). We should also investigate how scientific inquiry and science learning are related to imagination. However, imagination is not yet clearly defined in the science domain and there are various views of the role of imagination among researchers. We suggest the newly developed term of scientific imagination to focus on the role of imagination in science learning. Therefore, the concept of scientific imagination should be established to reflect the traits of science in order to utilize its value in learning science.

In this study, we propose a framework for scientific imagination and develop an inventory to validate the framework suggested as well as to evaluate students' scientific imagination. This framework and inventory for scientific imagination can guide the development of programs to enhance science learning with imagination. Therefore, this study aims to define scientific imagination and explore its elements. Such definitions of scientific imagination will help us to develop programs to stimulate the imagination after measuring imagination in students. To achieve these goals, we investigated the following two research questions: (1) What factors and dimensions comprise scientific imagination? (2) What are the characteristics of scientific imagination in Korean elementary and secondary school students?

Theoretical Background

Meaning of Imagination

This study aimed to define scientific imagination and to construct its framework. Before this can be achieved, it is necessary to explore the significance and educational value of imagination. In the traditional view, imagination can be described as (1) disrupting reason, and inferior to reason or (2) helping memory, performing a role in reproduction (Johnson, 1987). Thus, imagination has long been neglected as an interesting or important element of human mental activity, and has been ranked significantly lower than reason or judgment, faculties that it was thought to impair. However, imagination has come to be more favorably regarded as necessary to create and to perceive reality, not just the ability to create fiction or mimic extant phenomena. For example, according to O'Connor and Aardema (2005), imagination can be categorized as follows: (1) as a faculty, (2) as memory and or a picture in the mind, (3) as originality, creativity, and transcendence, and (4) as imageless imagination. In the modern view, imagination is essential to create and to perceive reality, and is a source of creativity (Barrow, 1988; Egan, 1992; Kant, 1980; White, 1990). Mary Warnock, a British philosopher, presented her philosophical analysis of the human activity of imagination in her book *Imagination* (1976). Acknowledging the contributions of Hume and Kant to our current understanding of imagination, she defined it as follows:

> Imagination is a power in the human mind which is at work in our everyday perception of the world, and is also at work in our thoughts about what is absent … Its impetus comes from the emotions as much as from the reason, from the heart as much as from the head. (Warnock, 1976, p. 196)

This indicates that imagination is an intrinsic, holistic approach of human beings to understanding the world. She insisted that imagination was the ability to appreciate the possibility beyond what we see, allowing man to perceive and experience the infiniteness before him. She also ascribed the ability to perceive and experience the subtlety or complexity of previous action to imagination. White (1990) also insisted that 'to imagine something is to think something able to become what it is'. Thus, imagination is not the ability simply to imitate or to form an image, but rather, it is the creative and innovative ability to produce new entities through reproducing past experiences and re-organizing existing realities. Likewise, in the modern view, the imagination is considered the foundation of mental activities such as thinking, and is considered necessary in human life. This study acknowledges these positive aspects of imagination.

We suggest two ways in which imagination can aid education, especially science education, based on reported opinions. First, it can enable students to take pleasure in learning and to reconstruct the knowledge they acquire. The imagination can be a diverse and rich source of educational material, with students feeling excitement and enjoying learning when their imaginations are stimulated in class. Making learning fun has many advantages (Egan, 1992). In addition, learning not only includes registering outside facts, but also includes configuring the material learnt (Egan, 1992; Vygotsky, 1998): students interpret new knowledge as elements they define themselves and relate it to their existing knowledge in their own way. Thus, imagination is necessary during re-componentization, configuration, and re-evaluation of meaning during learning (Warnock, 1976). Imagination is important in education to configure new knowledge based on experiences (Fettes, 2005; Gajdamaschko, 2005). Second, if the imagination is employed during education, it helps students develop emotionally. However, traditional school education focuses on the development of reason. Several scholars have argued that the imagination is closely related to feelings and emotions (Egan, 1992; Hume, 1888; Warnock, 1976). Imagination influences one's feelings and is also influenced by emotions.

Science Education and Imagination

Imagination is regarded as necessary in science for invention and for discovering new things. The current understanding of imagination—that it allows one to think of new possibilities and reconstruct meaning from previous experiences—is adopted here.

Shepard's (1988) research on the role of scientific imagination in famous scientists' major achievements showed that it was very important. Specifically, he asserted its productive and creative properties using the term 'scientific imagination'. Kim, Mun, and Mun (2009) suggested that scientific imagination greatly influences thinking, especially relating to intuitive thinking in science. They also stated that employing scientific imagination in science education did not mean simply creating images with a scientific background, but emphasized its productive aspects: creating new things and producing results. The authors also analyzed the results of recent interviews with scientists and found the following: first, scientists' imaginations help them look at the nature beyond the existing frame or with new perspectives, second, the imagination has definite goals and affects research topics, third, imagination facilitates the consideration of reality based on scientific knowledge, fourth, various experiences, curiosity, and wonder act as the driving forces of scientists' imaginations (Mun et al., 2013).

In this study, scientific imagination is considered to encompass scientific knowledge, creative thinking, and productivity. Its scientific characteristics are emphasized by accepting that it has a major impact on scientific results and on scientists' abilities to create products. In addition, scientific imagination includes the traits of general imagination, since it is a part of general imagination. Thus, scientific imagination is ultimately defined as the ability to think creatively in order to create or solve problems based on the understanding of scientific concepts or phenomena, past experiences, and scientific knowledge, thus including the view that imagination is related to feelings and emotions (Egan, 1992; Warnock, 1977; White, 1990).

A literature review revealed three traits of scientific imagination. First, it includes the traits of general imagination. The imagination is related to cognitive abilities such as memory and reasoning (Barrow, 1988; Egan, 1992). It also affects emotional feelings, may be stimulated under the influence of such feelings (Egan, 1992; Warnock, 1977; White, 1990), and is closely associated with previous experiences (Vygotsky, 2004). Second, scientific imagination is closely related to creativity. Scientific imagination includes creative reconstruction based on past experiences and scientific knowledge (Warnock, 1977). These features, as shown by many scientists, are the basis of new scientific creations (Shepard, 1988) and scientifically imaginative pupils will produce originative and creative results. Finally, scientific imagination has productive features, unlike fantasy, and is strongly employed when creating something new. In addition, one's sense of reality, the result of scientific imagination, has to be generally consistent with reality based on newly acquired scientific knowledge. In other words, scientific imagination includes reality by eliminating the reproduction of emotions caused by reality in the majority of people. The results of interviews with scientists also strongly support the structure of scientific imagination: emotional feelings, creativity, and reality (Mun et al., 2013).

Framework of Scientific Imagination

We reviewed the literature related to imagination to define scientific imagination and construct its dimensions. Scientific imagination is deeply related to scientists' achievements (Shepard, 1988). Mun et al. (2013) interviewed Korean scientists and identified three key dimensions of scientific creative imagination: scientific sensitivity, scientific creativity, and scientific productivity.

Scientific sensitivity refers to the driving force that enables one to imagine. It stimulates students' imagination with scientific concepts, knowledge, or natural phenomena, and encourages them to have a passion for imaginative activities (Ren et al., 2012). Imagination is closely related to human feelings and emotions (Ribot, 1906; Vygotsky, 2004). Liang, Chang, Chang, and Lin (2012) emphasized that creative imagination imply human emotional elements and they named it 'sensibility'. Also, scientists' curiosities, interests, and reverence for nature make them commit to scientific activities and help them manifest their imaginations (Mun et al., 2013). As curiosity and interest in environmental phenomena and scientific events stimulate the scientific imagination, scientific sensitivity has the characteristics of a driving force.

Scientific creativity is defined as traits that appear as pupils use their imagination. Creative imagination involves the process of creative problem-solving (Wieslawa, 2003). Scientific creativity incorporates traits of imagining scientifically, not only collecting a variety of related materials, but also engaging in trying to solve problems and having a passion for intellectual activity. Imagination allows us to see old characteristics in new relations and to form new relations from old ones (Liang et al., 2012). The characteristics of scientific imagination are that it helps pupils find new problems and also to find new and appropriate methods to solve them. Ren et al. (2012) described originality, richness, and flexibility as characteristics of creative imagination. In this study, we consider scientific creativity to include traits that emerge while imagining scientifically.

Finally, scientific productivity refers to the ability to generate new ideas. Scientific imagination becomes most meaningful when used to create new things. Many scientific achievements occur because of the use of imagination (Kind & Kind, 2007; Shepard, 1988). These achievements include transforming existing things and reinventing as well as creating new things. Creating something requires recognition of what is possible through scientific practice and scientific logic, not impractical imagination. Especially, scientific imagination is different in that it is based on science knowledge, and scientists obtain new results through the realization of imagination (Mun et al., 2013). Therefore, the scientific sense of reality is an important attribute that distinguishes scientific imagination from fantasy or delusion.

Methods

In order to examine factors of scientific imagination and to understand the scientific imagination of Korean students, we developed an inventory, which we called the Scientific Imagination Inventory (SII), and administered it to grade 4th–8th students alongside an exam factorial construct using exploration factor analysis (EFA). We went through the following phases.

Phase 1. Developing the Items of the SII

First, we identified factors of scientific imagination and developed an initial inventory to measure scientific imagination.

Step 1: Identifying factors of scientific imagination. In order to develop a questionnaire to measure pupils' scientific imagination, we analyzed the meaning of three elements in the dimensions of scientific imagination in more detail (i.e. scientific sensitivity, scientific creativity, and scientific productivity), and attempted to identify sub-components based on the literature and iterative discussions among researchers.

The scientific sensitivity. Scientific sensitivity refers to the driving force that enables students to imagine. It stimulates scientific imagination for scientific concepts, knowledge, phenomena, and events, and includes passion for scientific activities. The sub-dimensions of scientific sensitivity include 'emotional understanding' and 'the experience of imagination'. 'Emotional understanding' refers to the ability to understand scientific concepts and phenomena with a sense of emotion. This is reflected in the view that imagination is closely related to human feelings and emotions (Csikszentmihalyi, 1996; Liang et al., 2012; Ribot, 1906; Vygotsky, 2004). By understanding that scientific knowledge is the product of human creativity, energy, passion, hope, fear, and so on, scientific knowledge and phenomena can be emotionally accessible. Smith and Mathur (2009) also insisted that imaginative children tend to have the ability to regulate their emotions.

'The experience of imagining' is necessary for one to imagine scientifically and it refers to the ability to consider unusual and extreme things with interest and curiosity, or to think about phenomena that are far from reality. It includes characteristics of elementary and secondary pupils focusing on and imagining extreme and unusual things, according to Egan (1992). In this regard, Taylor, Carlson, Maring, Gerow, and Charley (2004) reported that children who engaged in impersonation showed higher scores on measures of emotion understanding than children who did not. 'Thinking of something that exists as if it does not', 'thinking of something that does not exist as if it did', 'considering a particular thing as if it were human', and 'thinking outside the general process of production' are included among 10 kinds of learning activities in the study of imagination proposed by Lee, Park, and Chung (2003).

The scientific creativity. Scientific creativity incorporates characteristics of imagining scientifically. Scientific imagination is important when creating new things (Ren et al., 2012; Wieslawa, 2003). Scientifically imaginative pupils possess originality and passion for intellectual activities relating to science. Thus, the abilities to create or solve problems emerge as a result of scientific imagination. In this study, creativity was considered as the procedural nature of scientific imagination. The sub-dimensions of scientific creativity were 'originality' and 'diversity'. 'Originality' refers to uniqueness, not thinking in standard or stereotypical ways, but thinking differently. This can be considered a procedural aspect of scientific imagination necessary for creating or producing something new. 'Diversity' refers to the enthusiasm for scientific activities and the tendency to explore relevant data in detail. It also involves the total sum of imaginative thinking. In the process of imagining scientifically, pupils demonstrate intellectual passion, such as being deeply engaged in scientific activities and working on a problem until it is solved.

The scientific productivity. Scientific imagination is useful when one has a purpose and uses it to produce something new. The sub-dimensions of scientific productivity are 'creation and reproduction' and 'scientific sense of reality'. 'Creation and reproduction' include the desire to find new methods or create new things, to see things differently after transforming them, and to find methods of solving problems using scientific knowledge. Such productivity distinguishes scientific imagination from fancy. Passmore (1998) regarded imaginativeness as 'disciplined fancy', implying that it is possible to convert fancy into scientific imagination. Productivity also includes a scientific sense of reality. Scientific imagination can be distinguished from fiction or delusion only through purpose and productivity. Therefore, productivity is the most important aspect of scientific imagination. 'Scientific sense of reality' means understanding whether imagined things are possible in reality. It is a unique feature of imagining scientifically. Many scientific inventions and discoveries were once considered impossible. However, because scientists had proper scientific senses of reality, they recognized the possibility of realizing their projects and so could achieve the seemingly unachievable. Scientific imagination, through the scientific sense of reality based on scientific knowledge, should help establish whether what is imagined can be made real.

Step 2: Developing initial items. Based on our work in step 1, we designed an initial inventory of scientific imagination for pupils. Three to 5 items were chosen for each sub-dimension, with 29 items in total. Each item was developed to fit the specified dimensions. In developing the initial items, we reviewed available instruments that aligned with our framework including: imagination indicator (Liang et al., 2012); test of creative imagination (TCI) (Ren et al., 2012); ability of an imagination scale (Lee, 2008). Liang et al. (2012) created an indicator of imagination with two dimensions: creative imagination and reproductive imagination. The indicator used a six-point Likert scale and was analyzed using principal component analysis and confirmatory factor analysis. Results showed that creative imagination consisted of novelty, productivity, sensibility, intuition, focus, and exploration, while reproductive imagination includes effectiveness, dialectics, crystallization, and transformation. Ren et al. (2012) defined creative imagination as 'the process of creative problem-solving and is related to creativity, a process through which new, original and valuable entities are produced'. They identified the characteristics of creative imagination and developed TCI based on the characteristics. TCI contains a drawing section and a word section. The drawing and word sections comprised scores for the following four dimensions: richness, flexibility, profundity, and originality. They administered TCI to 4,320 Chinese middle/high school students and reported the development of creative imagination in Chinese students. Lee (2008) developed an imagination scale for art education. The instrument consisted of 38 scales with 5 dimensions: imagination ability on sensible imagination, feeling and sentiment, situation, fanciful imagination, and product imagination. The instrument used 5-point Likert scales and was administered to 490 elementary school students to determine the construct validity. We referred to these instruments as necessary to modify our original 29 statements. The items were designed to be easily understood by elementary or secondary school pupils. We used a 5-point Likert scale (1: strongly disagree; 2: disagree; 3: uncertain; 4: agree; and 5: strongly agree) which was adapted to measure psychometric phenomena (Gable & Wolf, 1993).

The initial items included 11 items for scientific sensitivity, 10 for scientific creativity, and 8 for scientific productivity. The items were developed in Korean. For content validity, the developed inventory was evaluated by a panel of experts in science education. Each member of the panel gave their independent assessment of whether each statement was adequate for the purpose and whether the items in each scale were adequate for each dimension of scientific imagination.

Phase 2. Assessing Reliability and Construct Validity

We conducted EFA to test the validity of the SII. We administered the 29 items to 662 elementary and secondary school pupils from 2 elementary schools and 2 secondary schools located in the capital city, Seoul, and 1 secondary school located in Kyonggi, surrounding the capital city. A class was chosen randomly from each grade. Three hundred thirty-six participants (99 4th, 119 5th, and 116 6th graders) were elementary school students and 326 (143 7th and 185 8th graders) were from a secondary school. The majority were interested in science and showed a willingness to participate in scientific activities. We explained the research briefly to teachers and obtained their agreement to use the response materials. The test was completed in 10–15 min.

All the SII items were scored on a 5-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). The inventory was analyzed using SPSS version 18.0. Cronbach α scores greater than .70 were considered as indicative of acceptable reliability (Hair, Anderson, Tatham, & Black, 1995). After checking the reliability of each factor using the Cronbach α coefficient, items that decreased the reliability of each factor were removed. In addition, properly correlated items (ranging from .5 to .8) were selected.

Exploratory principal-components factor analyses followed by Varimax rotation and Kaiser Normalization were performed on the inventory. We used the eigenvalue to determine the number of factor extracts greater than 1 based on the Kaser–Gutten criterion. Six factors were found to be interpretable. Throughout the factor analysis, only items that loaded onto 1 factor with values above .40 were retained (Floyd & Widaman, 1995; Ford, MacCallum, & Tait, 1986). Nine items failed to achieve suitably high loadings on any factor and, therefore, were removed. The factor analysis was recomputed with the remaining 20 items (See Appendix). A 6-factor model explained 52.4% of the total variance in the 20 items. The six factors included the following: emotional understanding (EU) and the experience of imagination (EI) under scientific sensitivity, originality (O) and diversity (D) forming scientific creativity, and creation and reproduction (CR) and scientific sense of reality (S) comprising scientific productivity.

The internal consistency reliabilities using the Cronbach α coefficient was .79 for all items. The Cronbach α coefficients for each factor are presented in Table 1. The correlation among the 6 factors ranged from .20 to .46, and the correlation between the 3 dimensions and each factor ranged from .27 to .84. Matching items for each dimension were averaged to calculate a score for each dimension. The results of the three dimensions showed that the internal consistency reliabilities of each dimension were

Table 1. Factor analysis for 20 Likert-type items

Conceptual component	Factor	Total variance after rotation (%)	Cronbach α	Item	Factor loading
Scientific sensitivity	Factor 4: Emotional understanding (EU)	8.61	.572	E1	.659
				E2	.656
				E3	.596
				E4	.512
	Factor 2: The experience of imagination (EI)	9.46	.595	T1	.702
				T2	.647
				T3	.601
				T4	.543
Scientific creativity	Factor 3: Diversity (D)	8.64	.598	D1	.736
				D2	.719
				D3	.566
	Factor 5: Originality (O)	7.65	.514	O1	.715
				O2	.550
				O3	.456
Scientific productivity	Factor 1: Creation and reproduction (CR)	10.64	.634	CR1	.683
				CR2	.676
				CR3	.557
				CR4	.539
	Factor 6: Scientific sense of reality (S)	7.43	.254	S1	.727
				S2	.719

.67 for scientific sensitivity, .55 for scientific creativity, .62 for scientific productivity, and .79 for all items. The results for the reliability coefficient suggested that there is an acceptable level of internal consistency for the six factors. The mean scores of each item ranged from 2.47 to 4.39, whereas the mean scores of each dimension ranged from 3.33 to 3.67.

Phase 3. Analyzing Scientific Imagination in Korean Students Using the SII

We compared individual dimension scores and total scores according to students' gender and grade using one-way analysis of variance (ANOVA) to evaluate scientific imagination and the three dimensions. We used parametric statistical techniques to check the normal distribution of data and homoscedasticity in order to measure attitude, awareness, and other psychological factors in the Likert scale (Gable & Wolf, 1993). The patterns related to differences in the total SII and each dimension's mean scores across gender and grades were analyzed.

Results

The developed inventory was administered to elementary and secondary school students to understand their level of scientific imagination. The mean total SII score was 3.50. Among the three dimensions, students presented the highest mean scores for scientific sensitivity ($M_s = 3.67$), but the lowest mean scores for scientific productivity ($M_p = 3.33$). The mean score for scientific creativity was 3.47, while the total mean score for all scientific imagination items was 3.50. Since SII employed a five-point Likert scale, the mean scores were quite positive. Students appeared to have a driving force to imagine.

Comparison of SII Scores by Grade

The one-way ANOVA results showed that there are statistically significant differences according to grade levels (Table 2). Among all grades level, the 5th graders showed the

Table 2. Mean scores and standard deviations for SII scores by grade

Dimension	Total ($N = 662$)	Grade 4 ($N = 99$)	Grade 5 ($N = 119$)	Grade 6 ($N = 116$)	Grade 7 ($N = 143$)	Grade 8 ($N = 185$)	F	p
SII total	3.50 (0.49)	3.60 (0.43)	3.65 (0.52)	3.64 (0.47)	3.33 (0.47)	3.38 (0.46)	12.37	0.00
Scientific sensitivity	3.67 (0.62)	3.65 (0.55)	3.81 (0.66)	3.77 (0.63)	3.54 (0.63)	3.62 (0.59)	6.34	0.00
Scientific creativity	3.47 (0.61)	3.60 (0.61)	3.62 (0.58)	3.62 (0.60)	3.26 (0.60)	3.35 (0.57)	15.41	0.00
Scientific productivity	3.33 (0.60)	3.53 (0.57)	3.49 (0.62)	3.50 (0.54)	3.15 (0.55)	3.14 (0.58)	22.05	0.00

highest SII total mean score, while the 7th graders had the lowest. The results showed that elementary school students (Grades 4–6) had relatively higher scores than middle-school students (Grades 7–8). Table 2 and Figure 1 show that the total SII score continued to increase from 4th to 6th graders, peaked in 6th graders, and began to decline in 7th graders. Therefore, the pattern for mean scores by grades showed a decrease between the 6th and 7th grades. We conducted *post hoc* analysis to test for statistical significance in this difference between 6th and 7th graders. The result of *post hoc* Scheffe test (Table 3) showed that there were no statically significant differences between 4th, 5th, and 6th graders, but the difference between 7th and 8th graders was statistically significant.

We identified similar patterns throughout all three dimensions of scientific imagination. Scientific sensitivity had the highest mean score and scientific productivity had the lowest score for all grades (Figure 1). From these results, we can make assumptions about what aspect affects scientific imagination in students when they move from elementary to secondary school. Especially, 7th and 8th graders had lower scores for scientific creativity and scientific productivity. Elementary school students responded that they often wondered about novel things that others did not care about ($M_{O2,\ elementary} = 3.79$) and thought differently when solving problems ($M_{D2,\ elementary} = 3.75$). However, secondary school students seemed to have more difficulties with forming new ideas ($M_{CR4,\ secondary} = 3.28$) than elementary school students. The average value for all 20 items of scientific imagination for elementary school students was 3.67, while the average was 3.40 for secondary school students, showing a significant difference ($p < .01$) in scientific imagination between the age groups. The elementary school students scored higher than the secondary school students in all dimensions ($p < .01$), showing that elementary school pupils possess more curiosity and wonder, as well as intellectual passion for scientific activity compared with secondary school pupils. These results might be due to a lack of opportunities to experience various activities related to science in secondary school compared with elementary

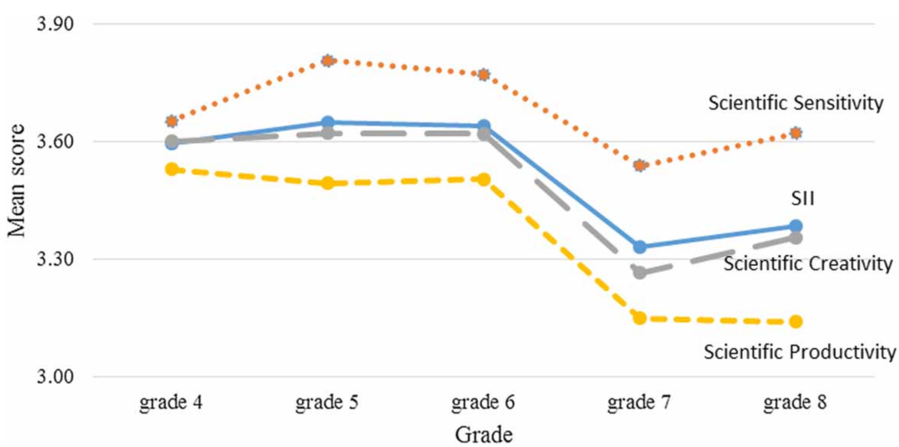

Figure 1. Patterns of mean scores of dimensions by grades

Table 3. Mean differences and *post hoc* Scheffe test by grade ($N = 662$)

Grades	SII	Scientific sensitivity	Scientific creativity	Scientific productivity
4–5	−.05	−.15	−.02	.03
4–6	−.04	−.12	−.02	.02
4–7	.27**	.11	.33**	.38**
4–8	.21	.03	.24	.39**
5–6	.01	.04	.00	−.01
5–7	.32**	.27*	.36**	.35**
5–8	.26**	.18	.27**	.35**
6–7	.31**	.23	.35**	.36**
6–8	.25**	.15	.26**	.36**
7–8	−.05	−.08	−.09	.01

*Significant at the .05 level.

**Significant at the .01 level.

school. Secondary school students possess much lower intellectual passion and curiosity to study science. These results are consistent with previous studies showing that the higher the grade, the lower the interest in science. Imagination tends to decrease in older students. This result is similar to previous results by Ribot (1906). In the creativity dimension, the younger students scored significantly higher than the older students, both in diversity and originality.

Comparison of SII Scores by Gender

As shown in Table 4, the one-way ANOVA results revealed statistically significant differences in mean scores of SII by gender. Female and male students had the highest score in scientific sensitivity and the lowest in scientific productivity. For all SII items, female students scored significantly higher than male students ($M_{female} = 3.53$, $M_{male} = 3.45$, $p < .05$). Female students had higher scores than male students in the dimension of scientific sensitivity ($p < .001$). For the scientific creativity and

Table 4. Mean scores and standard deviations for SII by gender

Dimension	Males ($N = 300$)	Females ($N = 362$)	F	p
SII	3.45 (0.50)	3.53 (0.48)	1.01	.033
Scientific sensitivity	3.56 (0.63)	3.75 (0.60)	5.75	.000
Scientific creativity	3.43 (0.65)	3.49 (0.57)	0.59	.208
Scientific productivity	3.34 (0.60)	3.31 (0.61)	0.07	.671

Note: Numbers given within parentheses indicate mean scores (SD).

scientific productivity dimensions, however, there were no significant differences in mean scores by gender. This finding is not congruent with the literature that presents gendered views of scientific imagination and creativity (Park et al., 2011). Park et al. (2011) examined the level of creativity in Korean elementary school science-gifted students and the results showed that female students had significantly higher creative potential than male students. However, in the study by Kim, Chung, and Lee (2003), there were no significant differences in creativity by gender for science-gifted students.

However, as evidenced by Table 5, the mean scores of five factors were significantly different by gender. In scientific sensitivity, females had significantly higher scores than males for EU ($p < .01$) and EI ($p < .01$). In scientific creativity, female scored significant higher than males only for the originality dimension ($p < .05$).

For scientific productivity, differences were investigated according to sub-dimensions. Male students scored higher than female students in CR ($p < .01$). On the other hand, female students had higher scores for scientific sense of reality ($p < .01$). These results indicate that the characteristics of scientific imagination differ between genders.

We also compared the mean scores of each item in the three dimensions of scientific imagination by gender to fully understand the cause of the differences. The results are as follows.

Scientific sensitivity. Table 6 represents mean scores and standard deviations of several items for scientific sensitivity according to gender. For the EU2 item, even though there were significant differences between female and male students, both groups scored higher on this item than on other items ($M_{EU,male} = 4.51$, $M_{EU,female} = 4.24$). However, for the EI4 item, female students reported sometimes thinking in reverse, as 'if they were a boy' ($M_{EI4} = 3.43$), while male students rarely thought like

Table 5. Mean scores and standard deviation for each factor by gender

Dimension	Factor	Males ($N = 300$)	Females ($N = 362$)	F	p
Scientific sensitivity	Emotional understanding	3.61 (0.78)	3.77 (0.66)	5.75	.00
	The experience of imagination	3.52 (0.79)	3.73 (0.76)	7.51	.00
Scientific creativity	Diversity	3.50 (0.80)	3.47 (0.69)	0.09	.69
	Originality	3.37 (0.79)	3.51 (0.75)	3.35	.02
Scientific productivity	Creation and reproduction	3.58 (0.81)	3.34 (0.72)	9.49	.00
	Scientific sense of reality	3.01 (0.71)	3.29 (0.78)	12.33	.00

Table 6. Examples of items for scientific sensitivity

Items	Mean (SD) Male	Female	*p*
EU2. Animals such as dogs and cats are able to feel emotions just like me	4.24 (1.01)	4.51 (0.74)	.000
EU3. I feel as if elements of nature, such as animals or plants, are my friends	3.08 (1.22)	3.32 (1.10)	.008
EI4. It is interesting to think in reverse, such as 'if I were a girl (or boy)'	3.43 (1.32)	2.75 (1.40)	.000

female students ($M_{EI4,male} = 2.75$). With regard to these results, Lindsey and Colwell (2003) reported positive associations between high levels of pretend play, emotional regulation, and emotional competence for female preschool children.

Scientific creativity. There were no significant differences by gender for scientific creativity. However, as presented in Table 5, female students had higher scores on originality than male students ($p < .05$). Especially, as shown in Table 7, female students were more likely to entertain unusual ideas ($M_{O1,\ female} = 3.42$) than male students ($M_{O1,\ male} = 3.08$). Male students seemed to consider problems based on various perspectives. Female students had higher mean scores for the item 'I am very happy and excited when I find the answer to a question.' This result indicates that there are differences in creative ability characteristics between female and male students (Kim, 2009; Loo & Shiomi, 1997).

Scientific productivity. The results showed significant differences for creation and recreation in the scientific productivity domain. Male students scored higher than female students, as shown in Table 8. Male students demonstrated a better ability to recognize the transformation of objects, and were more curious to determine the reason for the transformation. In contrast, female students scored higher than male

Table 7. Examples of items for scientific creativity

Items	Mean (SD) Male	Female	*p*
O1. I often hear that I am really odd or very unusual	3.08 (1.30)	3.42 (1.23)	.001
D1. I try to find answers as often as possible	3.57 (1.03)	3.42 (0.95)	.046
D3. I am very happy and excited when I find the answer to a question	3.81 (1.05)	3.96 (0.91)	.046

Table 8. Examples of items for scientific productivity

Items	Mean (SD) Male	Mean (SD) Female	p
CR1. I can easily tell when an object is rearranged or rotated	3.52 (1.03)	3.20 (0.95)	.000
CR2. I was so curious to understand the principle of something that I disassembled or assembled it	3.64 (1.29)	3.04 (1.22)	.000
S2. Magic or wizardry is not real, but is trickery	2.81 (1.41)	3.32 (1.35)	.000

students with scientific sense of reality items. For example, for the S2 item 'Magic or wizardry is not real, but is trickery,' female students had a mean score of 3.32 (SD = 1.35) while male students had a mean score of 2.81 (SD = 1.41).

The students' mean scores for scientific imagination were relatively high, with a mean value of 3.55 (the highest score is 5.00). The averages for all 20 items were slightly higher for female students ($M_{\text{female}} = 3.53$) than for male students ($M_{\text{male}} = 3.55$), but not to a significant degree, as shown in Table 2. Among the dimensions of scientific imagination, there were significant gender differences ($p < .01$) for scientific sensitivity in all factors (Table 3) and also for productivity (Table 5). Under scientific creativity, female students scored highest in scientific sensitivity and lowest in scientific productivity. Male students had the highest score in scientific productivity and the lowest score in scientific creativity. From these results, we can conclude that the characteristics of scientific imagination may be different between genders.

However, we found that females had higher mean scores for originality, and this difference was significant (Table 5). Thus, we can assume that females possess higher ability than males in the adaptive creative style. This result is in agreement with results from the Kirton Adaption-Innovation Inventory (Loo & Shiomi, 1997). It is also consistent with the results of the Torrance tests of creative thinking (TTCT) geometry test (Kim, 2009). In most studies on differences in creativity according to gender, there were no consistent results on gender differences (Kim, 2009; Kim et al., 2003). Therefore, for the balanced development of scientific imagination, it is necessary that science teachers or instructors understand the differences between genders, help males cultivate the ability to understand feelings and emotionally perceive objects and propose projects to ensure their scientific sensitivity is fully utilized as in female students.

Discussion

The primary aim of this study was to describe the characteristics of scientific imagination and to validate an inventory for measuring students' scientific imagination with Korean elementary and secondary school students. In this study, we developed an inventory and applied it to elementary and secondary school pupils to evaluate their scientific imaginations. Several studies have attempted to capture or investigate the role of imagination in the classroom (for more details, see Hall, Hall, & Leech, 1990; Wood & Endres, 2004). For example, Wood and Endres (2004) focused on the IEPC (imagine, elaborate, predict, and confirm) strategy and reported that having students imagine material specifically related to what they learned can be a powerful motivator of children's interests. Imagination enables students to enjoy learning and to learn to re-evaluate and meaningfully reconstruct what has been learnt (Egan, 1992). It is also important in the process of memorization, and enables students to think freely by providing flexibility, power, and vitality to human reasoning (Egan, 1992; Warnock, 1976). In order to emphasize the important role of imagination in science education, we propose the new term and framework of scientific imagination. The framework and instrument we developed for scientific imagination can guide the development of educational implications for understanding the relationship between science learning and imagination. Based on our results, the following can be discussed.

First of all, we suggested that scientific imagination consists of scientific sensitivity, scientific creativity, and scientific productivity based on previous research. Scientific sensitivity enables scientific imagination through the stimuli of scientific concepts, knowledge, phenomena, and events. Elements of the scientific sensitivity dimension are 'emotional understanding' and 'the experience of imagining'. Scientific creativity is defined through traits that appear during the process of imagining, and by characteristics that appear during and as a result of scientific imagination. The elements of scientific sensitivity are 'diversity' and 'originality'. Scientific productivity also consists of the two elements: 'creation and reproduction' and 'scientific sense of reality'.

Second, the SII developed here comprises 20 items. The overall reliability of the tool was .915 and the reliability of each of the three dimensions was $\geq$.5. The correlation coefficients of the items in each dimension were above .5. All 20 items were loaded to each dimension. The inventory consists of six factors, with each component confirmed as valid for its measuring goal. However, further research is needed to enhance the validity of the inventory.

Third, the result of comparing students' grades showed the depression of scientific imagination in the 7th grade after increasing until the 6th grade. This may be influenced by specific factors that students experience during graduation from elementary school and entrance into secondary school. Entering secondary school means moving to a new environment, and students must adapt to the changes. Also, the educational environment in Korea may account for the rapid decrease of imagination in the 7th grade compared to increase in the 4th–6th grades. In Korea, elementary school science education places more emphasis on various science-related activities, such as Science-Arts Integration (Jeong & Kwon, 2008; Yoon, Na, & Jang, 2004), science drawing (Park & Lee, 2010), and imaginative writing (Yang, Lee, & Noh, 2014), in order to develop students' imagination and creativity. Therefore, we can assume that elementary school students have more opportunities to think imaginatively. In this regard, Wright (2009) suggested that storytelling can help develop the imagination of young children as well as inspire learning and improve reading skills. Shmukler (1982) also found that imaginative predisposition and expressive imagination in play were related to the development of imagination in students. On the contrary, most classes in secondary school are oriented toward college entrance exams. This means that secondary school science classes are more focused on lectures rather than science inquiry activities and are designed to accustom students to learning science concepts. The rapid decrease of imagination in 7th graders indicates that lecture-centered science classes lead to the loss of students' interest in science itself.

Fourth, we found gender differences in specific dimensions. Based on the results, we suggest that teachers consider the differences between genders to improve students' imaginative abilities. For example, teachers should try to help male students cultivate the ability to understand feelings and to emotionally perceive nature. On the other hand, we can provide a learning environment that helps female students improve cognitive skills and ideas related to scientific productivity.

Finally, we can conclude that scientific imagination has educational value and potential application in science education. The definition, dimensions, and scale for measuring scientific imagination developed in this study through theoretical exploration and practical tests can aid the use of scientific imagination in science education. The educational value of scientific imagination can be understood through its application and methods of employing imagination in science education should be explored in future research. Also, teaching and learning should recognize the importance of feelings and emotions. The inventory developed here shows a positive correlation between scientific imagination, scientific sensitivity, and scientific creativity. Therefore, as students develop their emotions and sensitivities, they can enhance abilities related to creativity and scientific imagination. Therefore, it is imperative that teaching incorporates the emotional aspects of science education as well as its logical aspects. For this purpose, science teachers should understand the nature of pupils' scientific imagination and work to stimulate and develop those emotions.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix. Mean scores, and standard deviations of SII items ($N = 662$)

Item	Mean	SD
Scientific sensitivity	3.67	0.62
Factor 4: Emotional understanding	3.70	0.72
E1. The individual that first created what I am using is a wonderful person	3.79	1.10
E2. Animals such as dogs and cats are able to feel emotions just like me	4.39	0.88
E3. I feel as if elements of nature, such as animals or plants, are my friends	3.21	1.16
E4. When I look at clouds in the sky and trees, I think it is incredible	3.40	1.20
Factor 2: The experience of imagining	3.64	0.78
T1. I often think in terms of 'if I did … '	3.95	1.04
T2. I think about the opposite situation to reality such as 'if there is no air … '	3.45	1.17
T3. I often find myself imagining different things	4.03	1.00
T4. It is interesting to think in reverse, such as 'if I were a girl (or boy) … '	3.12	1.40
Scientific creativity	3.47	0.61
Factor 3: Diversity	3.48	0.74
D1. I try to find answers as often as possible	3.07	1.01
D2. When the problem is not easy to solve, I try to find a new way to solve it	3.49	0.99
D3. I am very happy and excited when I find the answer to a question	3.89	0.98
Factor 5: Originality	3.45	0.77

(*Continued*)

Appendix. Continued

Item	Mean	SD
O1. I often hear that I am really odd or very unusual	3.27	1.27
O2. I often wonder about things that others do not	3.70	0.98
O3. I do not use existing things, I am likely to change it in some way before using it	3.38	0.97
Scientific productivity	3.33	0.60
Factor 1: Creation and reproduction	3.45	0.77
CR1. I can easily tell when an object is rearranged or rotated	3.35	1.00
CR2. I was so curious to understand the principle of something that I disassembled or assembled it	3.31	1.28
CR3. When I find the principle behind something, I recall a situation containing it	3.49	1.06
CR4. It is exciting to create new things or solve problems	3.65	1.10
Factor 6: Scientific sense of reality	3.16	0.76
S1. I think events such as 'Harry potter' can actually happen	2.47	1.24
S2. Magic or wizardry is not real, but is trickery	3.09	1.40