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An instrument for measuring scientific empathy in students' disciplinary engagement: the scientific empathy index

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A crucial component of disciplinary engagement for learners in science is that of scientific empathy—in other words, the metaphysical connection between the student and the object of study, as scientists embody when deeply engaged in their work. Scientific empathy is the factor that stimulates and maintains students' desire to inquire and that elicits creative problem-solving in their "doing" science as a distinctive disposition from general empathy. As such, in this study, the scientific empathy index (SEI) was developed to measure these traits of scientific empathy. For this purpose, two-rounds of factor analyses were conducted in the preliminary and the main tests of SEI. To prove the validity of the main test, correlation and mediated analysis were additionally conducted between other problem-solving scales and Final SEI. The first-factor analysis was conducted on 1,048 elementary, middle, and high school students as a preliminary test for extracting SEI questions. Based on the preliminary test results, 956 K-12 students were newly recruited, and the validity of the main test was confirmed through a second-factor analysis. Through these analyses, it was identified that the scale comprised five factors: sensitivity, situational interest, scientific imagination, empathetic concern, and empathetic understanding of others. Each scientific empathy factor revealed both cognitive and affective process dimensions including individual and social interrelations of students' empathy in doing science. SEI was more highly correlated than the general empathy scale in the process of creative problem-solving and science process skills. In addition, it was found to exhibit a mediating effect between creative problem-solving and scientific inquiry. These findings validate the newly developed SEI and how it contributes to providing science learners with a useful tool for quick and easy measurement of scientific empathy and its components for the empathized involvement process between the student and their research subject.

KEYWORDS

scientific empathy, creative problem-solving, scientific inquiry, empathy scale, assessment

1 Introduction

Key documents that declare the vision for K-12 science learning, including National Research Council [NRC] (2012) and Next Generation Science Standards [NGSS] Lead States (2013) advocate the need for students to engage in science in a way that reflects the work of scientists to develop disciplinary skills To develop students' science proficiency, the opportunity to think, behave, and act as scientists should be provided to them. One of the biggest concerns among science educators about this vision is the declining participation and engagement in science among adolescents. Science, as a discipline for problem-solving (Hudson, 1958), needs to stimulate students' motivation in the inquiry process for students to continue to participate in this process (Krapp and Prenzel, 2011; Oh and Han, 2021). The research regarding the motivation inherent in disciplinary experience is pervasive in accounts of scientists' careers and pursuits (e.g., Watson, 1968; Keller, 1983; Feynman, 1985; Root-Bernstein, 2002; Gruber, 2005; Root-Bernstein and Root-Bernstein, 2013) as well as student inquiry (e.g., Engle and Conant, 2002; Duckworth, 2006; Jaber and Hammer, 2016b). Recent studies of students' motivation have revealed that effective science learning can be accompanied by empathy, though this is usually not made explicit (Oh and Han, 2021).

Generally, as a psychological strategy that gives students active intrinsic motivation for learning (Zaki, 2014), empathy is defined as cognitive and emotional responses to others based on perceived meanings or emotions in situations as if they were one's own, which emphasizes cognitive and emotional characteristics in interpersonal relationships (Zeyer and Dillon, 2019; Davidson et al., 2020). Empathy is an element of human psychology that gives insights not only from the social aspect, through relationships with others, but also from the individual perception in pedagogy. This was revealed through the famous scientists' epistemic processes in science—as attested by scientists' cultural histories, biographies, and personal reflections—such as Barbara McClintock, Richard Feynman, and Albert Einstein (Root-Bernstein, 2002; Jaber and Hammer, 2016a,b). We argue that the best instructional way for students to experience, "think, behave, and act," in science is to learn what scientists feel when they engage in their work. Thus, applying empathy to scientific practice is a means to allow students to experience what scientists feel, which will allow empathy to play a role that sheds another light on successful science learning and helps in unfolding its full potential. Moreover, considerations about the role of values in science education necessitate the insight that including empathy is not only useful, but vital. After all, empathy in modern science education can be considered both a catalyst and an important method to stimulate students' scientific engagement.

Empathy in science education has some different traits from "empathy" as used elsewhere in psychology (Jaber and Hammer, 2016a; Chun et al., 2018; Yang and Kang, 2019; Davidson et al., 2020). When empathy is used in scientists' productive disciplinary engagement, Jaber and Hammer (2016a) noted that scientists have a deep connection with the subject through metaphysical feelings. Yang and Kang (2019) posited that cognitive and emotional complex aspects of empathy can add creative thinking to the logical process of discovering and proving scientific knowledge. If so, to utilize empathy as a strategy for students' engagement in science education, the empathy ability of science education—subtly different from general empathy—should be reflected in science teaching and learning by interacting with the scientific thinking habits (Gauld, 2005). However, since the origin of empathy began with Einfühlung in terms of Psychological Aesthetics and the term empathy has now been widely studied in psychology and neurology as related to motor mimicry, imitation, and the perspective-taking involved in the process of how we get to know the feelings and intentions of others (Cuff et al., 2016), there are some limitations in applying it to science education in a pedagogical sense. When applied to science education, general empathy—empathy based on social context with others—the educational value is limited to the social aspect of the learner in the restricted content of social science issues such as Zeyer and Dillon (2019). As mentioned above, empathy in scientific problem-solving can be an optimized strategy for eliciting creative problem-solving solutions through metaphysical relationships, so the aspect of empathy, including intra-perspective should also be reflected in science education.

Some studies to confirm the intra/inter perspective value of empathy as a problem-solving process in students doing science were also recently conducted. In order to explore the factors of empathy in science education, the Interpersonal Reactivity Index (IRI, Davis, 1980) was used as an analytical framework for scientific empathy in studies that explored the prior research of scientists' empathy (Yang and Kang, 2019) or the scientific empathy factors based on core competencies for next generations (Chun et al., 2018). Both studies addressed scientific empathy by research participants in the problem-solving process in terms of the cognitive and emotional aspects and individuals and the interrelations of others. The reason for applying IRI to these studies is that it was assumed that empathy had complex characteristics of cognition and emotion and recognized various aspects of the four factors of empathy [e.g., Perspective-taking (PT), Fantasy (FN), Empathic Concern (EC), and Personal Distress (PD)]. While IRI has been validated for the general public (Albiero et al., 2009), the scientific empathy extracted from the studies based on the IRI both of the author and her colleague and of Chun et al. (2018) did not lead to the development of a test tool that could practicably be applied to students participating in science classes. For their research to be used as a new strategy within the context of science education, an instrument to conduct empirical research on scientific empathy factors that researchers have extracted first must be confirmed.

The aim of the present study is to enable future studies about how students' scientific empathy stimulates motivation in the inquiry process by developing and validating a scientific empathy index (SEI) suitable for science education. To this end, this study sought to verify the validity of the construct and criteria of the SEI based on the relevant studies referring to the traits of scientific empathy. Firstly, in terms of construct validity, qualitative and quantitative analysis is essential to clarify the definition of scientific empathy and to analyze the factors extracted based on the protocols and the characteristics of scientific empathy inherent in the constituent questionnaires (Hubley and Zumbo, 2013). Secondly, in terms of the criteria validity of the tool, the analysis process should be designed based on the two potential psychological traits of scientific empathy—scientists' empathy and problem-solving aspects—that can be assessed through previous research assumptions. To establish the value of the developed SEI as an empathy test tool, it is necessary to examine concurrent and discriminant validity evidence to confirm the similarities and further distinctions with the psychological empathy scale through data analysis. This analysis will determine whether the SEI distinguishes itself from other empathy scales and demonstrates its validity as a reliable assessment tool (Hubley and Zumbo, 2013). This process allows us to compare the components and traits of the SEI to a general empathy scale. On the other hand, we can also see the impact of the psychometric properties of scientific empathy on students' cognitive processes of inquiry. In other words, it is to ensure the validation of the psychological state of scientists who derive creative problem-solving based on proficient inquiry skills for the discovery and accumulation of knowledge reflected in the SEI. We can seek the relationship between SEI and scientific inquiry skills and creative problem-solving. While various accounts discussed psychological empathy, the considerations, for the most part, have not been the epistemically productive way (Jaber and Hammer, 2016a,b). That is, they have not been directed toward understanding learners' productive practice for applying to science education. Ultimately, as a growing area of interest in philosophy, the role of empathy in knowledge development through scientific practice requires more attention. Given that the IRI, adopted in previous studies that extracted the factors of scientific empathy, is a tool that is often used in psychological empathy, it makes sense to figure out the relationship between the extracted scientific empathy factors and the problem-solving process which is the means of knowledge generation.

This paper comprises three parts: First, we will discuss how scientific empathy has been conceptualized to motivate students' inquiry through its epistemic role in productive disciplinary engagement. Second, we explain methods for data collection and analysis to develop and validate SEI. Third, we will discuss findings to examine the relationship between SEI and other problem-solving instruments. It concludes with implications for research, specifically with regard to cultivating scientific empathy in science education utilizing SEI.

1.1 Scientific empathy in scientists' disciplinary practices

When scientists engage in knowledge-building or solving problems, scientific empathy with their actions, motivations, and behaviors plays an important role in their scientific thinking habits. In his account of "aesthetic cognition" in science, Root-Bernstein (2002) mentioned the feelings used by scientists to perform their mental calculations are as follows:

> Many of the best scientists acquire such a complete, "feel," for the systems they study that they report being able to, "become," part of the system, imagining what it is like to experience the world from the perspective of some component. Philosophers have labeled this cognitive process, "empathizing," or, "sympathizing." (Root-Bernstein, 2002, p. 67).

An implicit understanding of the relationship between cognitive and emotional psychological states of scientists in their scientific work and thinking habits—the processing of objectivity, rationality, and emotional neutrality (Gauld, 2005), is required for conceptualization in order to apply it to science education.

As scientists engage in the pursuit of scientific knowledge, an integral part of that engagement is the presence and influence of empathetic experience within such work. Scientific empathy is not just ancillary to scientific research, but rather it is a part-and-parcel feature of the experience of scientists as they engage in scientific inquiry (Yang and Kang, 2019). Though historians and philosophers of science have not fully explored the importance of scientific empathy in scientific pursuits, autobiographical and cultural accounts of scientists and naturalists are replete with evidence of affect as part of their scientific work (see; Root-Bernstein, 2002; Jaber and Hammer, 2016a,b; Chun et al., 2018).

Describing and defining scientific empathy as a structure is by no means a straightforward task. It is safe to assert that even in the empathy domain, the parent of scientific empathy, it is typically associated with cognitive and affective traits. Studying empathy has been problematic for researchers as there seems to be no clear consensus on its exact constituents (Zaki, 2014; Cuff et al., 2016; Zeyer and Dillon, 2019; Yang and Kang, 2020). Empathy is a fairly new idea in the field of science, as it was an introduced as a structure in the psychological aspect to more generally refer to the cognitive and emotional experience of recognizing others' situations as one's own, while pursuing a solution when faced with a problematic situation (see; Chun et al., 2018; Davidson et al., 2020). It is difficult to find evidence in existing studies of the exploration of scientific empathy, which reflects scientists' experiences. This is because the educational reflection of the experiences of scientists so far has only presented examples of scientific pursuits based on historical, philosophical, or social accounts of science, and the cultural, biographical, and anecdotal spreading of scientific work. The nature of scientific empathy is more difficult to explore, as it requires close attention paid to the ways in which scientists internalize and motivate the experiences, they feel in the process of engaging in disciplinary work. That is, for the definition of scientific empathy, a broad exploration of the metaphysical feelings within the lens of empathy that scientists feel as they participate in disciplinary work in those cases is essential. In turn, this study aims to define scientific empathy centering on the research that discussed the motivation and internalization process that can be experienced through the metaphysical connection[1] between the researcher and the research object that occurs during scientific disciplinary engagement.

1.2 Defining scientific empathy

Evidence gathered from scientists' cultural histories, biographies, and personal reflections shows that scientific empathy, as motivation for engagement, infuses disciplinary practices. This study's definition of scientific empathy was derived by following a similar set of procedures previously laid out by Gruber (2005). It is defined by synthesizing the preceding studies on empathy by analyzing the biographies and ethnographies of scientists' creative works and the motivation of their disciplinary practices. The commonality drawn from the previous research is that "scientific empathy is the process of creatively promoting problem-solving within the inquiry, utilizing empathy." In this vein, we suggest that scientific empathy is a deeply involved process in which scientists produce results as creative outputs based on their scientific proficiency. Based on the evidence derived from this process, scientific empathy is defined as the process of seeking creative solutions in scientific practice by becoming one with the object of research. This requires sensitivity toward a problem, imagination, and interest in research objects, as well as cognitive and emotional interpretation of the condition of others. We organized the discussion around five themes to describe scientific empathy: sensitivity, situational interest, scientific imagination, empathetic concern, and empathetic understanding of others.

First, sensitivity is defined as acceptance of a given phenomenon from a critical and diverse point of view while maintaining psychological suspicion and discomfort. In case studies of the disciplinary engagement of scientists, sensitivity was shown to play an important role in discovering problems and at the beginning of scientific discipline engagement. This is related to Lavoisier's detection of the imperfections of Stahl's phlogiston theory (Yang and Kang, 2019, p 256) and Darwin's later attempt to resolve the discomfort that he felt in Henslow's lecture on the characteristics of the climbing plant through further research (Darwin, 1887, p 126). Watson experienced a similar feeling when reviewing Pauling's paper, which published a model for DNA structure:

> At once I felt something was not right. I could not pinpoint the mistake, however, until I looked at the illustrations for several minutes. Then I realized that the phosphate groups in Linus' model were not ionized, but that each group contained a bound hydrogen atom and so had no net charge. Pauling's nucleic acid in a sense was not an acid at all (Watson, 1968, p. 102).

We argue that if analyzed through the lens of scientific empathy, this sensitivity is a triggering factor for scientific empathy that emerged in scientists' deep scientific engagement. Authors' research (2019), which categorized empathy factors in the scientists' problem-solving process as cognitive and emotional traits, explained that this sensitivity has emotional characteristics. They described that sensitivity has a close characteristic to personal awakenings among the elements of scientist empathy and reflects the point that scientists can recognize problems with more sensitivity than what ordinary people perceive (Yang and Kang, 2019, p. 256). In addition, in his 2005 research paper on the intellectual experiences of Darwin and other scientists, Gruber found that this sensitivity can lead to a change in scientific practice, and Duckworth's (2006) research on students' disciplinary engagement noted that students need to develop this sensitivity toward problem recognition during their deep engagement while doing science.

Second, "interest in research objects" refers to the emotional characteristics of students who appeared as active participants through motivation and wonder at the process of problem-solving in complex scientific issues. A number of studies have mentioned this active interest as situational interest and suggest that this is a powerful predictor of participation (Singh et al., 2002; Osborne et al., 2003; Krapp and Prenzel, 2011; Renninger and Hidi, 2016). Situational interest arises between the task and the learner, triggered at the moment when the situation grabs the person's attention and motivates them to focus on the task at hand (Hidi and Renninger, 2006; Krapp and Prenzel, 2011). In certain scientists' anecdotes, situational interest toward research objects is represented as a common denominator of their disciplinary engagement process. We were able to identify this trait through Darwin's steady investigational attitude toward the creatures he encountered in his exploration on the Voyage of the Beagle as seen in his autobiography (Darwin, 1887), or by what the geneticist Barbara McClintock described as her pursuit toward understanding corn—comparing herself to "a child, because only children can't wait to get up in the morning to get at what they want to do," (Keller, 1983, p. 70). Feynman also (2008) described similar feelings about pursuing the study of physics in his autobiography—as he enjoyed the process as if he were playing and solving puzzles (Feynman, 1985).

Specifically, in terms of science education, Zeyer and Dillon (2019) noted that solving scientific problems in the specific context of societal issues arising from environmental or health concerns enhances students' emotional and cognitive empathy, stimulating their interest and willingness to engage in scientific participation. Since students' critical thinking is derived from empathy, it can be expected that moral commitment may be used for the common good. The situational interest, which is itself rooted in empathy, has social values and ethical implications for the community that can be acquired by students making decisions on scientific issues. From our position, empathy is a turning point in new competencies for scientific decision-making. Scientific empathy is revealed as a situational interest in which learners focus on disciplinary engagement through empathy processes when encountering scientific problems. This attribute is reflected in the study by Zeyer and Dillon (2019) in which students are motivated by solving problems and actively participate in classes through emotional empathy. It also synthesized the emotions scientists experienced during previous research outcomes where they were impressed by the research objects. The positive influence caused excitement and the scientists felt further motivated to study more through their empathic concern while solving the problem (Yang and Kang, 2019: Davidson et al., 2020).

Third, scientific imagination is a personal way of understanding phenomena in which the scientist perceives themself as though they were the research object or experiment by thinking about something that does not exist. McClintock described how she pictured herself as "a feeling for the organism" in this process:

> "When I was really working with them, I wasn't outside, I was down there. I was part of the system... these were my friends... As you look at these things, they become part of you" (Keller, 1983, p. 117).

In a similar fashion, Root-Bernstein described Einstein's account of this immersion in the research process through the feeling of being one with the subject of study:

> "He imagined himself to be a photon moving at the speed of light. 'Imagine what he saw and felt as a photon, then he assumed the role of another photon, and imagined what he

> experienced in the role of the first photon"' (Root-Bernstein and Root-Bernstein, 2013, p. 23).

Jaber and Hammer (2016a) regarded such an experience as an exemplification of one of the five epistemic affects, namely, empathy with the object of study, which emphasizes the scientist's emotional state. On the other hand, Root-Bernstein (2002) accounted for scientific imagination as a mental tool that stimulates scientific thinking. Such thinking—the means of insight obtained through empathetic intuitions rather than through logic—can be understood as a form of, "aesthetic cognition." In a similar vein, Chun et al. (2018) and the authors' own previous investigations (2019) of scientific imagination as the cognitive aspect of empathy suggested that scientists had a tendency to undergo a deep immersion process, solving problems through feeling as though they were themselves an object of study.

Finally, the abovementioned "cognitive and emotional interpretation of the condition of others," which we have classified as the fourth and fifth elements of scientific empathy, may be tentatively paraphrased as "empathetic understanding and empathetic concern for others," synthesizing cognitive and affective demonstrations of empathy in interpersonal relationships. Empathy psychologist Davis (1980) describes it as Perspective-Taking (cognitive aspect) and Empathic Concern (affective aspect), which embody the meaning of the complex process of cognition and emotion arising from interaction with others. In fact, each facet—the cognitive process of multi-perspective thinking as well as the emotional agitation stemming from compassion—are both implicated when students face a problematic situation in a particular scientific context. Scientific activities that aim for the discovery, accumulation, and transition of scientific knowledge, like other human activities, are also formed as these social endeavors through the above-mentioned interactions between individuals. In this scientific practice, the process of forming a social consensus is that the assumptions and theories established by oneself in the intellectual community to which one belongs can be persuasive to other community members as knowledge, and the individual can also be convinced by the knowledge established by others. The mutual exchange of scientific knowledge is possible only when there is an expectation of this empathetic communication, without which the dissemination of scientific knowledge is bound to be hesitant, just as Darwin had been reluctant to publish his new theory of evolution (Darwin, 1887; Gruber, 1974). The formation of social interaction for scientific problem-solving is rooted in understanding and concern for others and can facilitate disciplinary engagement in the extension of scientific knowledge. This reciprocal characteristic of empathy allows students to stand in the shoes of others by experiencing the cognitive aspect of thinking from various perspectives and the emotional agitation process through empathy with others. This is demonstrated in the way Watson purported to feel a bond with Crick that motivated him to constantly re-analyze the DNA structure. In this regard, Watson described, "You have to do what you like and hang out with scientists who can give and receive intellectual help. One reason competitors did not get to the double helix before us was because they were isolated" (Watson, 1968).

In summary, scientific empathy is the scientist's motivation to participate in the process of solving the problem. It starts with sensitivity to and situational interest in the problem and ends with scientific imagination. Throughout the process outlined above, empathetic concern and empathetic understanding with others arise. Accordingly, in this study scientific empathy might be deemed as the process of driving students into the scientific inquiry process. This line of work might have contributed insights into the established definition of scientific empathy and how students enact scientific empathy to engage the science context. To this end, the Scientific Empathy Index, which measures scientific empathy, should be able to check and predict students' engagement in doing science.

2 Research question and hypothesis

The scientific empathy mentioned in this study is merely a theoretical model that incorporates the components by analyzing the creative problem-solving examples that have emerged from scientists' disciplinary practices through the lens of empathy. To confirm the validity of this theoretical model, an empirical analysis process was required. Therefore, we examined whether the measure of this underlying theoretical model provides evidence to measure the characteristics of scientific empathy which induce creative problem-solving by sustaining and stimulating students' desire to inquire in scientific practice.

As part of our project, SEI questionnaires that can evaluate students' scientific empathy were drafted or empirically tested. They were evaluated in terms of their consistency regarding the structure of the underlying theoretical model of empathy—psychological properties in the professional performance of scientists. To fulfill these aims, we applied the theoretical considerations outlined above to formulate the following detailed series of goals, research questions, and hypotheses.

2.1 Evaluation of the underlying structure of scientific empathy

According to the aforementioned definition of scientific empathy, scientific empathy will consist of distinguishable factors. We were interested in having the underlying structure of the item pool forms based on a theoretical model of scientific empathy, and how each factor of scientific empathy is related to the dimensions of empathy with others and empathy with objects. Therefore, the first research question concerns the SEI construct's dimensionality. Bearing this in mind, the following predictions were derived:

> H1.1. The components of scientific empathy are five factors: empathetic concern, empathetic understanding, sensitivity, situational interest, and scientific imagination.

> H1.2. The five scientific empathy components form two empirically distinguishable dimensions.

2.2 Evaluation of SEI's psychometric properties

The SEI should be designed by mapping so that differences in variables related to scientific empathy are reliably reflected in item scores. Therefore, in this study, by comparing SEI's psychometric properties with those of empathy, we tried to scrutinize what psychological specificity of scientific empathy appears in students' problem-solving. Previous empirical studies have predicted that certain properties different from general empathy will be manifested in scientific empathy (Jaber and Hammer, 2016b; Zeyer and Dillon, 2019). This divination can be confirmed through correlation analysis with other psychological testing tools, and this can be predicted as follows:

> H2.1. SEI has properties of general empathy.

> H2.2. SEI is more closely related to scientific inquiry than general empathy is.

> H2.3. SEI is more strongly related to creative problem-solving than general empathy is.

2.3 Exploring the assumed role of scientific empathy in the problem-solving process

In the preceding research on each element that constitutes scientific empathy, it is mentioned that the elements of scientific empathy continue to intervene in order to seek creative problem-solving methods in the scientific inquiry process (Davis, 1980; Root-Bernstein, 2002; Sawyer, 2007; Jaber and Hammer, 2016a,b; Renninger and Hidi, 2016; Davidson et al., 2020). Therefore, we can predict what role scientific empathy plays in the scientific inquiry and creative problem-solving process as follows:

> H3.1. The direct effect of scientific inquiry ability on creative problem-solving will be insignificant.

> H3.2. Scientific empathy will serve as a medium for scientific inquiry's ability to influence creative problem-solving.

3 Materials and methods

For students to have the same experience regarding deep disciplinary engagement as scientists proficient in science, the students' problem-solving process requires a process of scientific empathy that allows them to immerse themselves in research subjects. Various records provide evidence that scientists such as McClintock, Einstein, and Morris build new theories and laws through creative thinking processes based on their scientific inquiry skills when they empathize with the subject (Root-Bernstein, 2002; Jaber and Hammer, 2016a,b). Thus, scientific empathy is a component that is closely related to not only creative characteristics but also scientific inquiry ability, and in order to confirm its validity, it is imperative to check the relationship between creative problem-solving ability and inquiry ability.

This study developed and validated a test tool that can measure scientific empathy that induces students to engage deeply in scientific practice. To this end, the design for this study method was divided into two main parts. The first is the development of the questionnaire through the factor analysis of SEI. The construction of SEI was derived by following similar development procedures of empathy scales previously laid out by Batchelder et al. (2017). Prior to factor analysis, the development of the SEI questionnaire was adapted to questions from the preceding research instrument (Chun et al., 2018), adding our understanding of scientific empathy. In the process of Exploratory Factor Analysis (EFA) by applying examination tools related to existing scientific empathy to 1,048 elementary, middle, and high school students, Items were corrected, or new ones were developed. In addition, the final examination tool selected was applied to the new K-12 group, and its construct validity was verified through EFA and Confirmatory Factor Analysis (CFA). The second part is to confirm the concurrent validity of SEI. We sought to identify the final confirmed SEI to be related to the potential characteristics of scientific empathy: general empathy, creativity, and scientific inquiry based on previous scientific empathy research. To this end, the relationship between the four tools was confirmed through correlation analysis using the Interpersonal Reactivity Index (IRI) as a general empathy scale, the Creative Problem-Solving Profile (CPSP) as a creative problem-solving scale, and the Test of science process skill (TSPS) as a scientific inquiry ability scale. Finally, the role of the developed final SEI was sought to be confirmed through mediated analysis in the relationship between creative problem-solving and scientific inquiry.

3.1 Procedure for construction of scientific empathy index (SEI)

3.1.1 Preliminary test of SEI

Scientific empathy index was developed to measure various aspects of scientific empathy, encompassing cognitive and affective components, and to further delineate empathy toward both individuals and objects. The initial step involved selecting a series of items that indexed components of scientific empathy toward individuals or objects and determining their effectiveness in capturing other-oriented and object-oriented empathy within scientific inquiry. Potential items for SEI were derived from the Empathy factors in Science Class (EfSC, Chun et al., 2018) questionnaires in the field, which includes items measuring both cognitive and affective empathy in the science classroom, leveraging the strength of well-validated and established measures. The EfSC comprises 35 questions, primarily divided into two dimensions: empathy with others across three factors (Perspective-taking; O-PT, Empathic concern; O-EC, Empathic arousal; O-EA) and empathy concerning problem situations across two factors

(Perspective-taking; P-PT, Scientific imagination; P-SI). To select the questions for use in SEI, the 35 items from the EfSC were examined using a sample of 1051 students. Based on the results, the quality of each individual item was assessed (N = 1051; 361 students in elementary school, 215 students in middle school, 475 students in high school). To identify any items causing response bias, the mean, standard deviation, skewness, and kurtosis of each item were analyzed using SPSS. Subsequently, the correlation between individual items and the sum of items, as well as the correlation between individual items and the sub-factors, were confirmed to assess the reliability hindrance. The mean of initial SEI items was all distributed within 1.5 to 4.5, and the standard deviation was in the range of 0.80 to 1.15. None of the items had a skew of a magnitude of $\pm$ 2.0 or higher, which is the recommended cut-off criterion (Curran et al., 1996). There was also no item that had kurtosis values of more than 2.0. A value of $\pm$ 3.0 or more is the excess kurtosis cut-off and indicates a large deviation from normality (Curran et al., 1996). However, three items with a correlation between the item and the total score of less than 0.30 can be predicted to have low factor relevance (Tabachnick and Fidell, 2013). In order to explore the factor structure of the initial version of SEI, a Common Factor Analysis using oblique oblimin rotation was run using SPSS statistical software as EFA. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.964, above the recommended value of 0.60 (Kaiser, 1974), and the Bartlett test of sphericity was highly significant (χ^2 = 18998.211, p < 0.001), indicating that EFA is appropriate for this dataset. The EFA revealed the presence of five factors, with eigenvalues exceeding Kaiser's criterion of 1, explaining 49.814% of the total variance which is under the recommended criteria (Suhr, 2006). As a result of factor analysis by designating five factors, the range of commonalities between items was from 0.147 to 0.649. There are four items whose commonalities were under 0.40, further confirming whether each question shared a common variance (Suhr, 2006; Osborne and Costello, 2009). Factor loadings ranged from 0.295 to 0.795. The items loading under 0.40 and double loadings were also allocated in factor loading. For these four questions, it is necessary to check whether there is a theoretical association between the assumed factors of the item's contents or whether there is a theoretical overlap between the items (Osborne and Costello, 2009).

3.1.2 Refined items for SEI

Maintaining the five-factor structure of SEI verified by the preliminary test results, the contents of 35 initial questions were reviewed. However, the content validity of these 35 items was compared against five categories based on the EfSC factors with subtle differences from factors of EfSC. The content validity of these items was initially evaluated by four researchers from the Department of Science education of K University (a pseudonym) who judged whether each item measured scientific empathy with others (O-PT, O-EC, O-EA), scientific empathy with an object (e.g., perspective-taking of the research object, feeling like part of the object), or none of these such as problem-solving drive (e.g., feeling interest, being sensitive to, wondering). The raters were provided with definitions of each category based on those provided by recent theories of scientific empathy (Chun et al., 2018; Yang and Kang, 2019) and rated each of the 35 items independently. If all four raters agreed on the choice of other-oriented or object-oriented scientific empathy for a given item, the item was included as part of SEI for further evaluation. In cases of disagreement, researchers re-focused on the definitions of scientific empathy to allow for further assessment and discussion. By omitting or rewording problematic items reflecting additional raters' comments about the item, repetition and ambiguity within the questions have been reduced (Rea and Parker, 2014). The items of all components were further subdivided into cognitive and affective within each component except for the problem-solving drive, which is a potential factor that cannot be classified as cognitive or affective factors. The same four researchers predicted that items measured one of the five components: cognitive scientific empathy with others, affective scientific empathy with others, cognitive scientific empathy with object, affective scientific empathy with object, or problem-solving drive. These items were categorized based on the following definitions which are deeply based on scientists' empathy in the inquiry (Yang and Kang, 2019). This resulted in 33 items identified as accurately measuring either scientific empathy with others (12 items) or objects (21 items). After evaluating this, five of the 35 EfSC entries were deleted, 15 were retained, and 15 were modified. In addition, three additional questions related to affective empathy with objects were created to reflect prior research in the case of empathy by scientists (Yang and Kang, 2019). In the case of revised or newly created questions, −1 was added to the question code (i.e., b0307-1, b0308-1, and b0309-1).

Lastly, based on the theoretical meaning of each factor, the final SEI constituent items were refined in a clear language associated with its features. The features of the five elements could be summarized as follows. First, we have cognitive empathy with others which is defined as empathy from the perspective of others and accommodating others' opinions. Second, affective empathy with others is described as recognizing and feeling heartache for others' failure in their emotional experiences. Third, cognitive empathy with objects is explained as a thought experiment, imagination based on observation, and feeling like part of the object. Fourth, affective empathy with objects is described as touching the subject, excitement in further study, and sensitivity to problems. Last, problem-solving drive is distinguished as motivated and goal-directed behaviors that tend to increase and operate based on positive reinforcement in the inquiry process (Zaki, 2014). That is, the factors of this questionnaire, which are semi-structured with five features, can be attributed to the five factors of scientific empathy based on the preceding studies in the aforementioned section on the motivation for the students' scientific practice: empathetic understanding-empathetic concern (Davis, 1980), scientific imagination (Root-Bernstein, 2002), sensitivity (Yang and Kang, 2019), and situational interest (Renninger and Hidi, 2016). A five-point response scale (1 = Strongly Disagree to 5 = Strongly Agree) was chosen to capture the differences in responses. The order of the items was then randomized to produce the first version of SEI.

3.1.3 Main test of SEI

The final SEI questionnaire was conducted on 988 students of five elementary, middle, and high schools independent from the preliminary test participants to confirm whether the finally determined items were valid. Of these, 956 data were collected, excluding 32 questionnaires with insufficient responses or insincerity. In the same phase of the preliminary test, the quality of the items was examined, and factor analysis was conducted to check the factor structure of the items. The mean of the final 33 items used in this test was all distributed within 1.5 to 4.5, and the standard deviation was all over 0.60. For skewness and kurtosis, all items except for one item (b0101-1) met the normal distribution condition (± 2), and all other items except for one item (a0302) in correlation between item-total scores were 0.30 or higher. As a result of calculating the KMO and the Bartlett test of sphericity to check whether 33 items are suitable data for factor analysis, KMO is 0.959 and the Bartlett test of sphericity is (χ^2 = 14365.706, df = 528, $p < 0.001$), confirming that this data is suitable for factor analysis. The number of factors that satisfy the eigenvalues exceeding Kaiser's criterion of 1 without specifying the number of factors and the number of factors presented in the screen plot were five equally. The number of factors tentatively derived by the researcher was also five, so five factors were finally extracted. The items loading of these extracted factors, except for 12 questions, showed commonality and factor load of 0.40 or more (Pett et al., 2003). As a result of the above test, among the items that did not meet the cutoff criteria of the procedure, 26 items were finally identified by removing seven items tied to factors different from the theoretical concept of the item. The final test tool consists of 26 items of five elements that show a commonality of at least 0.30 and account for 49.388% of the total variance.

Subsequently, exploratory factor analysis and confirmatory factor analysis were conducted to confirm the validity of the empathy scale (**Table 1**). Unlike the previous test, a confirmatory factor analysis was additionally performed on the final extracted items. To check the structural relationship between each variable and the factors, the fit of the model was verified using SPSS and AMOS software. All CFAs were based on examinations of the covariance matrices (Muthen and Muthen, 2006). We used maximum likelihood estimation, which adjusts the standard errors of the parameter estimates, and the chi-squared statistic (χ^2) to account for non-normality (Satorra and Bentler, 1994). We also used bootstrapping to extract empirical samples repeatedly to ensure model validity. We examined several indices of model fit, including chi-squared statistic (χ^2), comparative fit index (CFI; $0.90 \leq x \leq 1.00$), and root mean square error of approximation (RMSEA; <0.06) (Hu and Bentler, 1999). The following sections will address the process of verifying the concurrent validity of SEI. To this end, the correlation of final SEI with other measures (TSPS, CPSP) was checked, and the mediating effect between the scientific inquiry process and creative problem-solving process from scientific empathy mentioned in the theoretical background is analyzed. We employed the PROCESS macro for SPSS (Hayes, 2017) to test for mediation effects.

3.2 Validation of scientific empathy index (SEI)

3.2.1 Participants

Scientific empathy index was administered to a convenience sample of 956 elementary, middle, and high school students in five schools in three school districts in Republic of Korea. The sample included 314 elementary students (49.4% girls; mean age = 11.32, SD = 0.65), 404 middle school students (51.2% girls; mean age = 13.75, SD = 0.83), and 238 high school students (71.0% girls; mean age = 17.40, SD = 0.30). The initial survey, approved by the Institutional Review Board (IRB) of the K University (a pseudonym), was conducted as a self-assessment tool. Students completed the four sets of questionnaires under the supervision of their teacher. Three questionnaires were previously developed and validated, while the other was a test tool for scientific empathy to be developed through this study. One questionnaire was administered at a time; the questionnaires were sent out once per month. The time required per questionnaire was around 20 min. Data collection was completed in the spring of 2019. The description of measures used in the present analyses is summarized in the next section.

3.2.2 Measure

3.2.2.1 Interpersonal reactivity index (IRI)

The empathy scale used was Davis's (1980) IRI, which is divided into four subscales: Perspective-taking (PT), which measures the tendency to adopt others' viewpoints; Fantasy (FN), which measures the tendency to engage with novels or movies; Empathic Concern (EC), which measures the tendency toward interest, compassion, and warmth for others experiencing negative experiences; and Personal Distress (PD), which measures the tendency toward inconvenience and anxiety when seeing others' negative experiences. The four subscales consist of seven questions each, with 28 in total, each scored on a five-point Likert scale ranging from 0 to 4 points. This study used an exact translation of Davis's IRI to compare it with results obtained in other countries. To avoid misinterpretation, we used the Korean adolescents' version of Davis' IRI (Yang and Kang, 2020). Two statistical methods were used to check the reliability of the questions. The KMO value for the items was 0.907; the χ^2 in the Bartlett sphere formation validation was 11587.159; and the degrees of freedom (p) were 378 (0.000). In terms of subscale reliability, the Cronbach's α values were 0.756, 0.767, 0.735, and 0.757 for PT, FN, EC, and PT, respectively. These results confirmed that the measurement tools used in this study were reliable.

3.2.2.2 Test of science process skill (TSPS)

The Scientific inquiry ability test was conducted using TSPS, which was developed by Kwon and Kim (1994). The TSPS can be used for students ranging from 5th-grade elementary school students to 3rd-year middle school students in Republic of Korea and is made up of two subscales: basic inquiry ability and integrated inquiry ability. The science process skills presented in TSPS consist of five basic process skills for basic inquiry ability subscale: observing, classifying, measuring, predicting, and inferring. Five integrated process skills for integrated inquiry ability subscale were also covered: transforming data, interpreting data, controlling variables, formulating hypotheses, and generalizing. Each of the subordinate inquiry abilities of both two subscales consists of three questions for cognitive evaluation of inquiry ability with answers to be selected from four choices. Cronbach's α reliabilities of the two subscales (a total of 30 questions) typically range from 0.70 to 0.78, and the overall scale has substantial convergent and discriminant validity.

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TABLE 1 Result of confirmatory factor analysis (*sic*).

Factor		Questionnaire		Factor loading
Other	**SEI 2** empathetic concern	a0204-1	I'm worried about seeing a friend in a difficult situation during the experiment.	0.843
		a0203-1	I am a worried person when I see a friend lagging behind and struggling during science activities.	0.726
		a0202	It bothers me to see a friend who is ignored for no reason in a group activity.	0.635
		a0205-1	I feel uncomfortable for the failure of others' experiments.	0.388
	SEI 3 empathetic understanding,	a0106-1	I try to think about his perspective for a moment when I am angry with a conflict with another friend in the process of inquiry.	0.740
		a0107-1	Before I criticize a friend, who has different scientific opinions from me, I think about what I would do if I were in his shoes.	0.716
		a0102-1	I try to listen to other people's opinions even if there is something I believe is right during the experiment.	0.528
		a0104	I listen to many people's thoughts before making decisions about scientific experiments or inquiry activities.	0.405
Object	**SEI 4** sensitivity	a0302-1	I get the same feeling as them if my peers lose their aspiration toward the inquiry object.	0.636
		a0305-1	I feel uncomfortable with ambiguous problems.	0.484
		b0308-1	I feel nervous when the surrounding mood is in a tense atmosphere during the course of scientific inquiry.	0.482
	SEI 5 situational Interest	b0309-1	I have a question about a lack of explanation or an unsatisfactory solution.	−0.702
		b0208	Upon seeing a new phenomenon or sensing problem, I want to know the reason.	−0.663
		b0210	I take it with interest without avoiding new stimuli or trouble situations.	−0.604
		b0206	When I have a problem that interests me, I keep thinking about the problem in my head and figure out various solutions.	−0.583
		b0107	When I feel frustrated with the poor results of the experiment, I try to reflect about the process again.	−0.483
		a0103-1	I try to look at the problem situation from various perspectives	−0.446
		b0102-1	I try to change the way I think or solve a problem for an effective solution.	−0.411
		b0205	When I have a problem to solve, I easily fall into a problem situation and actively participate.	−0.393
	SEI 1 scientific Imagination	b0202	When I read an interesting science article, I feel as if I were in the situation.	0.877
		b0204	I imagine the incident as if it had happened to me when a scientific problem situation was given.	0.715
		b0201-1	When I read the scientific article, I imagine how I would solve this if this happened to me.	0.651
		b0203	I feel I become part of the research object when there are problems to be solved.	0.545
		b0108-1	Before criticizing the scientific hypothesis, I think about the research process of the scientists who claimed it.	0.396
		b0106	In order to better understand the problem situation, I try to think from the perspective of the study object.	0.376
		b0307-1	I am very impressed by the discovery of new facts and solutions.	0.352

	x^2(df)	CFI	RMSEA
Model 1 (1 factor analysis)	2841.577 (299)	0.758	0.094
Model 2 (5 factor analysis)	1104.893 (289)	0.922	0.054
Model 3 (hierarchical secondary factor)	1183.758 (293)	0.915	0.056

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3.2.2.3 Creative problem-solving profile (CPSP)

Creative problem-solving profile, which is based on the theoretical model of creative problem-solving style according to the problem-solving process (Basadur et al., 1990), was used to measure students' ability in the creative problem-solving process in this study. Basadur et al. (1990) said that the four factors that determine the type of creative problem-solving (experience, idea generation, thinking, and evaluation) have different effects on the performance of each step of creative problem-solving. A set of adjectives that correspond to the four above-mentioned factors constitutes each four-step in the CPSP: problem finding, idea generation, plan, and execution. The problem-finding step is affected by experience and idea generation, the idea-generation step is thinking and idea generation and the plan step is thinking and the idea evaluation, and the final execution stage is affected by the propensity of the experience and idea evaluation. Each question in the CPSP consists of adjectives corresponding to these four factors and is a self-report measure in which the examinee is required to indicate sequentially according to the degree to which he or she is thought to be similar. Since the CPSP by Basadur et al. (1990) was developed for English-speaking adults, Park Sunyoung and Choe Insoo's CPSP inventory was used to check the validity of creative problem-solving type for Korean adolescents, considering the language and age of this study. There is a total of 25 questions with each question to be answered having a four-point Likert scale. In terms of subscale reliability, Cronbach's α values were 0.745, 0.771, 0.811, and 0.751 for problem finding, idea generation, plan, and execution, respectively.

4 Results

4.1 Five-factor model

Scientific empathy index model provided an acceptable fit (CFI = 0.915, and RMSEA = 0.056). Factor loadings were significant and acceptable in empathetic understanding, sensitivity, and situational interest of SEI, ranging from −0.411 to 0.877. However, the factor loading of the four items in the remaining sub-elements (a0205-1 in empathetic concern as well as b0108-1, b0106, b0307-1 variables in scientific imagination) was under 0.40. Nevertheless, as indicated in **Table 1**, the value is only slightly lower than the standard. The Cronbach's alpha value for each factor ranged from 0.552 to 0.881, indicating high reliability for each factor within the model.

Based on the questions that make up each factor, the characteristics of each factor are analyzed in terms of cognitive, emotional, object-oriented, and others-oriented aspects as follows. Empathetic concern is the emotional empathy that research subjects experience through their relationships with others. This factor comprises negative emotional tendency items like concern, compassion, and anxiety toward others during the inquiry process (Davis, 1980), such as "I'm worried about seeing a friend in a difficult situation during the experiment." Empathetic understanding consists of a cognitive tendency to understand others by taking their psychological views or attitudes voluntarily. This area consisted of questions such as "I try to listen to

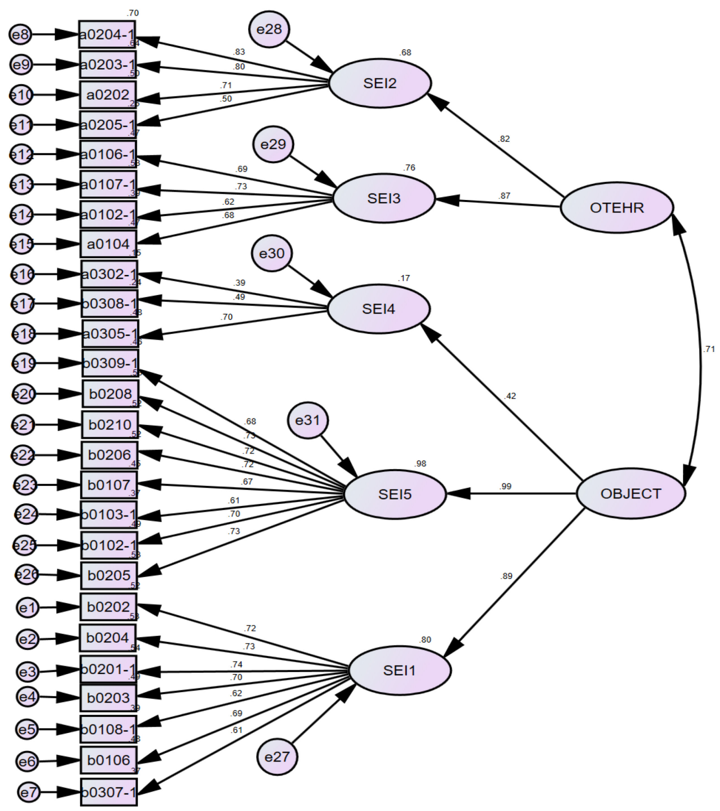

FIGURE 1
The hypothesized measurement model of the refined SEI. Model 3 (hierarchical secondary factor), χ^2 (293) = 1183.758, CFI = 0.915, RMSEA = 0.056.

TABLE 2 Comparison of Bivariate correlations between measures for SEI and IRI.

Measure	SEI					IRI			
	Other		Object						
	SEI 2	SEI 3	SEI 4	SEI 5	SEI 1	PT	FN	EC	PD
SEI 2 (empathetic concern)	1								
SEI 3 (empathetic understanding)	**0.563****	1							
SEI 4 (sensitivity)	0.284**	0.263**	1						
SEI 5 (situational interest)	0.511**	0.501**	0.196**	1					
SEI 1 (scientific imagination)	0.456**	0.441**	0.180**	**0.779****	1				
Interpersonal reactivity Index (IRI)									
PT	0.408**	**0.602****	0.142**	0.316**	0.278**	1			
FN	0.258**	0.192**	0.235**	0.292**	**0.355****	0.219**	1		
EC	**0.575****	0.434**	0.213**	**0.342****	0.316**	0.541**	0.369**	1	
PD	−0.091**	−0.183**	0.217**	−0.294**	−0.236**	−0.222**	0.085**	−0.116**	1
Creative problem solving profiled (CPSP)									
Problem finding	**0.435****	0.452**	0.202**	0.630**	0.567**	0.399**	0.381**	0.462**	−0.272**
Idea generation	0.402**	0.417**	0.178**	**0.691****	**0.618****	0.360**	0.323**	0.342**	−0.327**
Plan	0.371**	0.426**	0.184**	0.667**	0.582**	0.383**	0.247**	0.314**	−0.332**
Execution	0.410**	**0.478****	0.217**	0.619**	0.538**	0.442**	0.299**	0.445**	−0.286**
Test of science process skill (TSPS)									
Basic process skill	0.062	−0.003	0.090**	0.095**	0.039	0.014	0.081*	0.000	−0.019
Integrated Process Skill	**0.103****	0.067	0.059	**0.190****	**0.110****	0.048	0.070	0.010	−0.083*

Bold values in the table indicate elements that are relatively more significant compared to other sub-elements. The symbol '**' represents statistical significance at the 1% level ($p < 0.01$), indicating highly statistically significant results. PT, perspective taking; FN, fantasy; EC, empathic concern; PD, personal distress.

other people's opinions even if there is something, I believe is right during the experiment." to understand and accept the various viewpoints of others to make decisions during exploration. Sensitivity is composed of feelings of anxiety or discomfort felt by the empathizer from the problem situation (Yang and Kang, 2019). This factor is composed of an emotional tendency to detect problems in the context of problem solving such as "I feel uncomfortable with ambiguous problems." Situational interest originates between the task and the learner (Hidi and Renninger, 2006; Krapp and Prenzel, 2011), one of the epistemic affects (Jaber and Hammer, 2016a), and it is composed of a borderline disposition of cognitive and emotional empathy to find solutions from problems. This factor consists of the means to desire to know more, the drive to enter into the research object, and the building of deep connections between self and the natural world beyond the solution (Renninger and Hidi, 2016) such as "upon seeing a new phenomenon or sensing problem, I want to know the reason." Scientific imagination represents the tendency of the empathetic elements related to the individual cognitive processes of the research agent from research objects. It is composed of questions that imagine feeling like an organism through empathy with the research subject in a scientific problem-solving situation (Jaber and Hammer, 2016a) such as "I feel I become part of the research object when there are problems to be solved."

Table 1 summarizes the fit of each model and shows the results of the CFA using AMOS. The standardized regression weights of Model 1 were −0.028–0.718, of which eight items were significantly lower than 0.50. The fit of Model 2 extracted with 5 factors was satisfactory; the standardized regression weights for the five factors were found to be 0.341∼0.835. The standardized regression weights of two of these items (a0302-1, b03008-1) were less than 0.50. The fit of Model 3, where 5 sub-elements are hierarchized as 2 elements was also satisfactory; the 26-standardized regression weights for the five factors ranged from 0.387 to 0.798, whereas the five-standardized regression weights for the top factors ranged from 0.416 to 0.987. Moreover, no standardized regression weight of more than 1.0, but less than 0.5 were only found in three items (a0205-1, a0302-1, b03008-1). The difference between the χ^2 values of Models 2 and 3 was significant ($\Delta\chi^2$ (4, N = 956) = −78.865, $p < 0.005$), but that of the model fit was negligible (ΔCFI = −0.007, ΔRMSEA = 0.002). Especially, in the case of the RMSEA, the hierarchical secondary factor model (Model 3) was not rejected because the difference was significant when the change was greater than 0.015. This outcome indicated that the relationship between the five primary factors was somewhat explained by one secondary factor. See Table 1 for a full outline of goodness-of-fit test results for each measurement model. The final measurement model of the SEI is presented in Figure 1.

4.2 Correlations in SEI with IRI in terms of scientific discipline

Bivariate intercorrelations between SEI factors are shown in Table 2. Relationships were examined between all factors within the refined SEI to better understand these factors of scientific empathy.

Except for sensitivity, the remaining factors indicated a significant correlation of more than 0.30. In particular, they have identified a higher correlation in the realm to which they belonged than others such as the dimension of empathy with others and its sub-factors ($r = 0.868$–0.900), the dimension of empathy with the object, and its sub-factors ($r = 0.412$–0.951). Among the sub-factors, the following were found to be the most relevant: empathetic understanding and empathetic concern ($r = 0.563$), situational interest, and scientific imagination ($r = 0.779$). This seems to be closely related to the theoretical background of the realm of scientific empathy. That is, since empathetic understanding and empathetic concern are social empathy processes through interaction with others, it seems that the data analysis results also showed high correlation values. On the other hand, situational interest and scientific imagination seem to have revealed this high correlation due to the commonality of being empathetic with both the subject of research and the object by having the intention of the empathizer to solve the problem.

To confirm the concurrent validity of SEI as an empathetic measure, the correlation between the entire SEI and the entire IRI was confirmed, and a significant correlation of 0.40 or more was shown ($r = 0.413$, $p < 0.001$). As a result of checking the correlation between each sub-factor of SEI and each subscale of IRI, which is an existing empathetic scale, it can be confirmed that the sub-factors of SEI are closely related to the subscales of IRI that influenced the development of the questions of each sub-factor in SEI. IRI's PT is empathetic understanding to SEI, FN is scientific imagination, EC is highly correlated with SEI's empathetic concern, and PD, which showed a negative or weak relationship with the empathy factor in previous studies, showed the only positive relationship with sensitivity of SEI.

To explain the features of SEI related to scientific inquiry, and to confirm the difference with the general empathy scale, the correlation between SEI, CPSP, and TSPS was compared with the relationship between IRI, CPSP, and TSPS. Both SEI and CPSP showed a significant correlation, except for sensitivity, showing a significant correlation coefficient of 0.3 or more. However, although the correlation between IRI and CPSP is significant, the correlation coefficient value was 0.30 or less or was indicated as a negative relationship. The relationship between SEI and TSPS showed significant correlation compared to the relationship between IRI and TSPS, but overall, the correlation coefficient was weaker than the reference value.

4.3 Scientific empathy as mediator

To test the prediction that scientific empathy would be a mediator between scientific inquiry and creative problem solving we employed the PROCESS macro for SPSS (Hayes, 2017) to test for mediation effects. The PROCESS bootstrapping creates 5000 bootstrapped samples of randomly selected observations from the data, drawn with replacement (Hayes, 2017). Bootstrapping was used to verify the significance of the indirect effect of scientific empathy in science inquiry affecting creative problem-solving (Shrout and Bolger, 2002). Model paths were then estimated for each bootstrap sample, and results from these samples were then used to construct estimates and confidence intervals for each model path. Direct, indirect, and total effects with 95% confidence intervals were calculated using the PROCESS macro (Hayes, 2017).

As a result of verifying the significance of each pathway, scientific inquiry was found to have a positively significant effect on scientific empathy ($B = 0.363$, $t = 3.3254$, $p < 0.001$), but creative problem solving ($B = 0.0604$, $t = 0.9006$, $p = 0.3682$) did not show any significant results. However, scientific empathy was found to have a significant effect on creative problem-solving ($B = 0.6432$, $t = 32.5409$, $p < 0.001$). Results indicated that scientific empathy was a significant mediator between scientific inquiry and creative problem-solving. The direct, indirect, and total effects of scientific empathy as a mediator are presented in Table 3. As a result of the analysis, in the case of the path leading to creative problem-solving through scientific inquiry, it was found that the indirect effect and the 95% confidence interval did not include zero, so it was found to be statically significant ($B = 0.2335$, CI [0.0806∼0.398]). As expected, the direct effects of scientific inquiry on the outcome variables of creative problem-solving were small. However, the indirect effects of scientific inquiry on the outcome variables though the mediator variable were significant, indicating a mediation effect.

To conduct a deeper analysis of the effects of each sub-factor of scientific empathy on devising creative problem-solving in the scientific inquiry process, the mediating effect of each sub-factor of SEI was examined (Figure 2). In the conceptual model, all five sub-factors were considered as a mediating effect to derive creative problem-solving methods from science inquiry ability, but this hypothesis was partially corroborated; in the verification of the path to each sub-factor of SEI in scientific inquiry as predictors, empathetic concern ($B = 0.3058$, $t = 2.0465$, $p < 0.05$), sensitivity ($B = 0.5687$, $t = 3.8038$, $p < 0.001$), and situational interest ($B = 0.4947$, $t = 3.6991$, $p < 0.001$) only showed significant results. In addition, the results of the path analysis on whether each sub-factor affects creative problem-solving include scientific imagination ($B = 0.1145$, $t = 4.776$, $p < 0.001$), empathetic understanding ($B = 0.1005$, $t = 4.7841$, $p < 0.001$), and situational interest ($B = 0.3505$, $t = 12.8678$, $p < 0.001$) were found to have a significant effect. This analysis revealed that the rest of the factors except situational interest were weak predictors as putative parameters to mediate the effect between scientific inquiry ability and creative problem-solving. After all, it indicates that situational interest, of the five sub-factors, is the most important medium between scientific inquiry and creative problem-solving. This can also be confirmed in the verification of the direct, indirect, and total effects of the sub-factors of SEI as a mediator (Table 3).

5 Discussion

In this study, we sought to make a measurement of scientific empathy that would be incorporated to stimulate students' thirst for discovery and maintain participation in the process of disciplinary engagement. To this end, we explored and verified the components of scientific empathy by focusing on problem-solving (especially empathy, creative problem-solving, and science process skills) that students will experience in scientific practice. That is, the purpose of the present research was to develop and validate SEI, a new brief self-report measure of scientific empathy that produces a total scientific empathy score, as well as scores for a number

TABLE 3 Mediation analysis effects for scientific inquiry and creative problem-solving.

	Effect	*se*	*t*	*p*	95% CI's for indirect effect	
					Lower bound	Upper bound
Total effect	0.2939	0.0968	3.0362	0.0025	0.1039	0.4838
Direct effect	0.0765	0.0678	1.1277	0.2597	−0.0566	0.2096
Indirect effect						
Total of SEI	0.2174	0.0811			0.0599	0.3826
SEI 2 (empathetic concern)	0.0041	0.0079			−0.011	0.0218
SEI 3 (empathetic understanding)	0.003	0.0147			−0.0267	0.0322
SEI 4 (sensitivity)	0.0142	0.0107			−0.0038	0.0384
SEI 5 (wonder)	0.1734	0.0537			0.0724	0.2833
SEI 1 (Scientific imagination)	0.0228	0.0187			−0.0116	0.0622

Effects are from PROCESS macro for SPSS, with 5,000 bootstrapped samples. [1]The term 'metaphysical connection' denotes the in-depth investigative process undertaken by students when studying a subject or issue, comprehending and intertwining conceptual relationships and solutions through emotional and cognitive interaction to achieve a profound understanding.

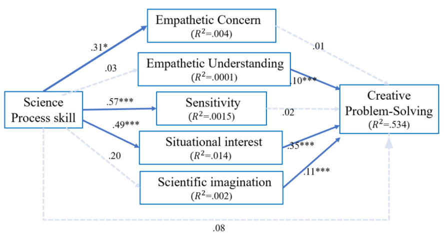

FIGURE 2
Observed path model reflecting the associations among the tested variables (N = 956). The science process skill is on the **left** while outcomes predictive are on the **right** (e.g., empathetic concern, creative problem solving). A Gray dotted line indicates paths that are not significant, and so are negligible. SEM model statistics: CFI = 0.917, RMSEA = 0.129, χ^2 (13) = 218.835, p = 0; thus, there was good fit. The symbols * and *** are explicitly defined to signify statistically significant results at $p < 0.05$ and highly statistically significant results at $p < 0.001$, respectively.

of relevant components within scientific empathy. In the study of Chun et al. (2018), the only existing study of the scientific empathy-related scale, items were selected using IRI as an analysis framework among the behavior indexes of core competencies for future generations. The factors were extracted by conducting a questionnaire survey with science teachers. In this study, however, as we judged that the items extracted through the above process would be different from the scientific empathy that students and scientists use, the validity of the scale was investigated by applying the items developed in Chun et al.'s (2018) research to actual students. In addition, the final selection of the items was analyzed based on what was mentioned in the Yang and Kang's (2019) study on whether each item, whose validity was confirmed as statistically significant by the above process, has a value as a component of empathy for scientists. Through this, we were able to confirm that the empathy factor used by scientists in problem-solving is also inherent in students, and this was presented as five crucial components: sensitivity, situational interest, scientific imagination, empathetic concern, and empathetic understanding with others. Scientific empathy factors predicted a closer relationship with the CPSP scale, which is the disposition of creative problem-solving, than the TSPS scale, which is the cognitive aspect of scientific inquiry. In addition, we have confirmed whether scientific empathy links the cognitive aspects of scientific inquiry to creative problem-solving.

Our research is possibly the first such study to identify factors enabling students to experience scientific empathy by establishing a metaphysical connection with the research subject, akin to scientists, during the scientific inquiry process. As such, it offers insights into crucial variables for students, seeking to blend creative problem-solving while incorporating scientific practices into classroom experiences. The disciplinary experience we advocate is deemed vital in science education in this era of standardization, as it intensifies students' immersion in scientific practices. Subsequently, we delve into the five key themes of students' scientific empathy identified in this study and their implications in science education. Furthermore, we conclude with a discussion highlighting the characteristics of this SEI in the problem-solving process, offering valuable lessons for curriculum developers and researchers seeking to support students' comprehension and engagement in the field of science, alongside considerations regarding how these experiences could mold students' scientific practices. Components of a deep connection between learners and subjects in scientific practice: Five scientific empathy factors.

The best way to pursue and build knowledge is learning through the experience of becoming the subject of study itself (Palmer, 2012). In particular, the importance of this metaphysical feeling in the process of scientists' epistemic inquiry has been mentioned in many studies through their problem-solving cases (see Root-Bernstein, 2002; Jaber and Hammer, 2016a; Chun et al., 2018; Davidson et al., 2020). However, there has been scant research that only vaguely mentions this experience as empathy and investigates it for science learners based on a clear analysis of its components (Oh and Han, 2021). In this study, based on the empathy characteristics of scientists mentioned in the Yang and Kang (2019) prior research, we defined the scientific empathy that can be engendered in students. Using the definition as an item analysis framework, a test tool was developed and its validity was verified for K-12 students who were directly related to it.

The five factors in SEI that have been verified in this way are composed of questions that describe the behavior of students who participate deeply in scientific practice with active motivation for inquiry. In other words, the five factors extracted from scientific empathy seem to be closely related to the process of students immersing themselves in science practice and proceeding to participate in scientific practice through the meaning of the constituent items. First, among the factors of scientific empathy, sensitivity is composed of questions about the emotional process that detects discomfort with a problem. The manifestation of this trait corresponds to the awakening of students to initiate scientific practice in the scientific problem-solving stage, in the same vein that scientists trigger discovering or sensing problems by their sensitivity. When this sensitivity comes from the relationship with others, it is anxiety from the problem situation of others' interaction; in the case of scientists, it is referred to as an empathic concern in empathetic research (Davis, 1980). The factor of scientific empathy, consisting of questions that reflect this content, is empathetic concern over others. The learner must immerse themself in the subject with a deeper metaphysical feeling after students pose and raise the problem—in the process of seeking a solution to the discovered problem—for deeper scientific participation. At this time, students experience the feeling of being a subject of study through their imagination or reflecting on the thoughts or positions of others through taking a perspective, which is a cognitive empathy mechanism. Scientific empathy factors composed of items that are deeply related to this cognitive empathy state are empathetic understanding of others and scientific imagination. Finally, scientists seek problems in order to solve them, motivated by constant curiosity, and undergo cognitive and emotional experiences to elicit this solution, which is closely related to situational interest. The items of this situational interest describe the process of active challenge in order to solve problems, persisting in working with an ongoing task in the scientific inquiry process.

The five SEI factors extracted as components of scientific empathy through this research are critical factors in the process of science learners stimulating inquiry motivation and establishing a deep connection with the inquiry process. These are meaningful because they are the first empirical findings of scientific empathy that identify the characteristics of scientists with K-12 students. Unpacking each characteristic, we demonstrate that the dynamics of students' engagement in "doing science" in scientific practices are possible through scientific empathy — psychological complexes of cognitive and emotional stimuli in both personal and social contexts in scientific inquiry. Based on this, scientific empathy will contribute to acknowledging the value of science education, triggering students' scientific practice as a factor in the formation and continuity of their disciplinary engagement, such as in solving scientists' problems. That is, components of SEI will play a vital role in inducing the disciplinary involvement of learners when developing or constructing a curriculum.

5.1 Strategies for deriving creative solutions in scientific practice: scientific empathy

Scientists' persistence in work their ongoing tasks entails not only logical reasoning but also an intuitive and creative aspect for the pursuit of the problem-solving process (Polanyi, 1958; Root-Bernstein and Root-Bernstein, 2013). In this study, these problem-solving mechanisms of scientists have been unpacked through correlation and mediated analysis that identifies the characteristics of scientific empathy. In terms of empathetic traits, all components of SEI have been shown to be significant values in correlation with IRI, thus proving that SEI is a complex process of cognitive and emotional components similar to IRI. In terms of problem-solving traits, the other complexity of SEI was also confirmed in the correlation between the cognitive test of scientific inquiry ability and creative problem-solving. SEI was more associated with scientific inquiry than IRI, but it did not show a strong correlation value. Rather SEI was ascertained to have a higher association with creative problem-solving. It can be putative that SEI measures the psychological process for creative problem-solving subtly adding the characteristics of scientific inquiry as a problem-solving test tool.

The above-mentioned two complexities, the intertwined duality of SEI, assist in deriving creative solutions based on the cognitive skills of exploration when solving the task. This study confirmed that scientific empathy has a mediated effect between scientific inquiry and creative problem-solving. In this vein, Kohut (1959) noted that when empathy is used as a tool in scientists' disciplinary practices, their logical thinking may be creatively reorganized to increase the depth and breadth of research carried out by scientific principles (Rifkin, 2009). In addition, empathy was being used as a medium to help scientists' objective knowledge extend to a new combination through creative thinking (Yang and Kang, 2019).

In recent science education endeavors, there has been enormous interest in learning how students enter into and sustain their engagement in scientific practices (NGSS; Next Generation Science Standards [NGSS] Lead States, 2013). Few studies, however, have expanded the area of interest to embrace whether students connected their science experience to creative problem-solving during the inquiry process. In comparison, by drawing upon our own research in analyzing the characteristics of scientific empathy through existing empathy and problem-solving scales, we confirmed that scientific empathy, leveraging the advantages of both empathy and problem-solving traits, serves as a bridge between logic and intuition in the inquiry process. These contributions will later assist science educators in designing scientific practices for an educational context that consider the creative problem-solving that is to be found in real scientists' engagement with their discipline.

5.2 Future directions and limitations

We acknowledge that our study has some limitations that give rise to fruitful possibilities and avenues for future research. First, one significant strength of this study lies in the cross-sectional design applied to a substantial K-12 student cohort, enabling the extraction of characteristics associated with scientific empathy at a specific moment. However, the measurements lacked the specific contexts within which students engaged in practical scientific experiences. Future studies could explore the evolving nature of students' scientific experiences during their educational engagement by creating suitable contexts to gauge their scientific empathy. It could be argued that the most effective means to measure scientific inquiry and problem-solving is through hands-on experiments, activities, and projects, illustrating how students develop and apply their scientific skills in more meaningful ways than theoretical lessons alone.

Second, while our survey was confined to Korean students, global education trends aim to promote engagement in scientific disciplines among all students, particularly in the United States. Future research might explore these findings by applying similar parameters across various cultural contexts.

Third, our study utilized various scales to analyze the intricacies of a novel concept—scientific empathy—and its association with problem-solving. While our results demonstrated a close link between SEI, empathy, and creative problem-solving, the significance of SEI concerning scientific inquiry ability remains uncertain. Therefore, upcoming studies should consider TSPS, the tool used in the current study to evaluate scientific inquiry ability. Criticism exists that the scientific process skill emphasized in the 90s, forming the foundation of TSPS, primarily focuses on measuring rational and logical thinking in scientific inquiry ability (Temiz et al., 2006). Hence, future research needs to consider tools that cover not only cognitive aspects but also emotional and social elements of scientific empathy, aligning with contemporary definitions of scientific inquiry ability.

Lastly, our subsequent efforts aim to fortify the Scientific Empathy Index by exploring its characteristics across diverse demographic groups, taking into account varying perceptions of scientific empathy across different age ranges. Additionally, we plan to investigate how attitudes toward science differ based on gender, considering a reviewer's observation of varying attitudes toward scientific inquiry between genders. These aspects will play a central role in our upcoming research endeavors, refining the Scientific Empathy Index, investigating demographic variances, and exploring gender-based differences in scientific attitudes.

6 Conclusion

The field of science education strives to ensure that all students understand and value disciplinary engagement in science as required by recent reform endeavors (National Research Council [NRC], 2012; Next Generation Science Standards [NGSS] Lead States, 2013). To do this, it is essential to design education so that students can experience firsthand what they think, do, and feel in science in a similar way to professional scientists. We argue that scientific empathy is a critical mechanism that can provide students with this experience. Namely, we desire to invite science educators to understand and emphasize the value of the cognitive and emotional psychological state, not the professional cognitive abilities that scientists already have; that the students need for their scientific practice as scientists engage deeply in their work. In a similar vein to our focus, research on cognitive, emotional, and social context variables for students to participate in scientific practice has been active in the science education community. Until now, however, there have been few studies on the scientific empathetic factors triggered when scientists engage in a metaphysical relationship with the research subject, nor how students immerse themselves in the inquiry process within science education. We believe this is a missed opportunity within the science education community that must be recognized, allowing engagement in science learning experiences from an early age. Application of SEI in program design to provide students with similar psychological experiences as scientists and to measure their conditions during scientific practice could greatly support their deep engagement in scientific practice. This itself calls attention to the importance of scientific empathy as not only a research endeavor but also scientific learning and scientific practice in the development of curriculums.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Korea National University of Education Institutional Review Board (IRB). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

HY: Writing – original draft, Writing – review and editing. DA: Writing – review and editing. S-JK: Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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