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RESEARCH-BASED TEACHING: ANALYZING SCIENCE TEACHERS' PROCESS OF UNDERSTANDING AND USING ACADEMIC PAPERS TO TEACH SCIENTIFIC CREATIVITY

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Abstract. *Postulating that academic papers can positively impact the actual teaching practices of science teachers, this study analysed the process of understanding and utilising academic papers by science teachers to teach scientific creativity in their schools. The 45–hour graduate course of three science teachers was explored to identify the difficulties teachers encountered in trying to understand academic papers and to discover how to solve these difficulties. Second, which aspects should be considered when developing teaching materials for scientific creativity to be used in schools were analysed. A transformation model of an academic paper was proposed to understand this process, and the results were organised accordingly. According to this model, it was emphasized to translate academic papers from a general and abstract state to a local and concrete state. Therefore, the role of science educators as knowledge translators was discussed for more practical and effective use of academic papers in school. This study is expected to contribute to research-based teaching by linking academic research with teaching practice.*

Keywords: *case study, research-based teaching, scientific creativity, teacher's learning process, teaching plan*

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Introduction

Many scientific education researchers believe and expect that their research can contribute to actual teaching practices in schools. Of course, not all science education research is directly connected to actual science teaching in the classroom, but these expectations and beliefs are quite plausible and encouraging (Bassey, 1992; Carden, 2004). Therefore, this study's main interest was understanding, in-depth, the process of science teachers' grasps of academic research papers and the use of them to change and enhance their own teaching practices.

Educators have stressed that teachers' reading and understanding of academic papers are necessary for developing teaching professionals (Zeuli, 1994); as such, they have encouraged this research-based or evidence-based practice (Biesta, 2007; Hirschkorn & Geelan, 2008; Traianou & Hammersley, 2008). That is, Hirschkorn and Geelan (2008) claimed that teachers should be able to access academic papers, develop the requisite skills needed to understand them, and improve their capacities to adapt and implement research results for changing and improving their teaching.

However, in real-world conditions, educational papers are not read well and used by teachers. Hillage et al. (1998, p. 45) argued that, although the purpose of many educational papers was to change and improve educational practices, teachers' actions were insufficiently informed by such academic papers. That is, teachers rarely seek out and utilise research-based knowledge to improve educational practices (Hiebert et al., 2002). Furthermore, education policymakers do not tend to use educational research that truly offers a high potential for enhancing science education (Zhang et al., 2022). Moreover, there is a case in which an experienced teacher even told a beginner teacher that it is better to eschew the professional knowledge developed through academic research and learned in college (Barnett & Hodson, 2001).

In fact, some may have questioned whether 'ordinary' science teachers should have the expertise to read and utilise abstract and difficult academic papers for their routine science teaching. This is because the two communities, one comprised of researchers and the other of practitioners, have dif-

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ferences in the values and purposes pursued, the language used, their reward systems, and so on (Caplan, 1979; Edwards, 2005; Farley-Ripple et al., 2018). For example, teachers' main concern is the practicality of research findings, whereas academic researchers pay attention mainly to generalising the outcomes, and failing to be sensitive to the various, specific, and practical variables involved in real-world teaching contexts. The language used by the two communities also differs; that is, academic papers often use complex academic terminologies with which teachers are unfamiliar (Bassey, 1992). Additionally, there is no teacher-friendly system by which teachers can easily access and use academic papers (Hirschkorn & Geelan, 2008). As a result, teachers see educational papers as yielding few practical results (Broekkamp & van Hout-Wolters, 2007) and as irrelevant to their practice (Kennedy, 1997).

As such, teachers complain that academic papers are so abstract and academic that they are impractical. Meanwhile, researchers are dissatisfied because academic papers that could contribute to teachers' practices are neither read nor used by teachers. This gap between research and practice in education has long been pointed out as a serious problem that is difficult to solve.

Therefore, research-based practice has attracted attention and has been recommended as a way to narrow this gap (e.g., Broekkamp & van Hout-Wolters, 2007; Grima-Farrell et al., 2011). For example, Broekkamp and van Hout-Wolters (2007) summarised the earlier efforts to reduce this gap, using four approaches. The first is to translate the abstract research into the form of concrete teachers' guides and distribute translations to teachers with the hope that more teachers will use them to improve their educational practices. The second approach focuses on empirical research to obtain evidence of efficacy. In this case, teachers conduct research themselves by using methods that have proven effective, such as randomised experimental methods. The third is for teachers, policymakers, and researchers to collaborate. In this way, teachers can contribute to the formation of research problems, and researchers can directly participate in the implementation; thus, a connection between practical and theoretical knowledge can be generated. The last approach is to make the third approach more systematic. This final option constructs a professional network system that connects people such as teachers, researchers, policymakers, and supporters in various fields, thereby generating new knowledge as well as exchanging and sharing information with each other.

However, despite these efforts, there is still a limit to ensuring that educational research is well connected to teaching practice in schools (Grima-Farrell et al., 2011; Honig & Coburn, 2007; Joyce & Cartwright, 2020). Therefore, this study began with an effort to understand this problem more deeply and glean insights to solve it on a practical level. More specifically, the main point of this study is to clarify the characteristics and difficulties that appear when reading, grasping, and applying academic papers by science teachers. Furthermore, this study addresses implications and offers insights for science teachers' research-based teaching. Because creating the link between research and practice is not possible only through teacher change and development (Hirschkorn & Geelan, 2008), as a teacher educator, researcher should also play a different role. Therefore, this research suggested the role of teacher educators with the aim of contributing to building the connection between research and practice.

With this background, the goals of this research were to:

(1) examine what difficulties teachers had in understanding academic papers and how such difficulties could be solved;
(2) identify which aspects should be considered in the process of using the academic papers to develop teaching materials for their science teaching;
(3) suggest the role of those who teach educators in helping teachers understand and utilise academic papers for their actual teaching practice.

Theoretical Background

Transformation Model to Connect Research with Practice

Educational research can be defined "broadly as the structures, processes, products, and persons that are part of the systematic development of knowledge of education" (Broekkamp & van Hout-Wolters, 2007, p. 205). In other words, the term 'research' encompasses institutions, such as universities and laboratories, where academic research is conducted; rigorous standards and procedures that research should follow; experts, such as professors and professional researchers; and research papers or reports that they have produced. Among them, this study confined research to academic research papers.

What is more, teachers' educational practice also includes a variety of aspects related to teaching, from examining curricula, students, and teaching environment, proposing instructional ideas, designing lesson plans,

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developing teaching materials, and implementing lessons in the classroom, to assessing and reflecting on teaching. In this study, educational practice is limited to science teachers' proposing instructional ideas and developing teaching materials.

The role of academic papers on educational practice has been generally discussed in two ways. One is to "describe, interpret or explain what is happening without inducing any (immediate) change" in education, and to "give a theoretical account" (Bassey, 1992, p. 5). For example, research that reviews and discusses student interest in science (e.g., Krapp & Prenzel, 2011) or explores the process of generating scientific hypotheses (e.g., Park, 2006) can provide new insights and a deeper understanding of students' science learning. Although this research does not report any direct achievements or improvements with regard to the specific educational purposes, it is expected that education can develop gradually through teachers' changed awareness and a reorientation in their dispositions.

The second goal of educational research is to "induce some change which they see as beneficial" for improving or changing educational practice (Bassey, 1992, p. 5). For instance, research that helps students' conceptual understanding by applying a learning strategy based on deductive thinking (e.g., Lee & Park, 2013) or that reports on improvements in students' scientific competency using online argumentation (e.g., Tsai, 2015) fall into this research role. Because this research offers evidence for developments and improvements in educational settings, the terms 'evidence-based' and 'research-based' are also used.

These two roles of educational research provide the basis for understanding the two types of research-practice relationships, as described by Trianou and Hammersley (2008): the enlightenment model and the engineering model. In the case of enlightenment model, teachers learn about new ideas, gain new insights, or grasp new implications from the research. Through these new ways of looking at the world — which have gained by reading the research — education can be gradually and cumulatively changed and improved (Nutley et al., 2003; Weiss, 1977). Similarly, Farley-Ripple et al. (2018) called this a 'conceptual use of research', which can contribute to a change in one's knowledge about, understanding of, and attitude towards education. As such, it is expected to be able ultimately to change education in a practical way.

For the engineering model, it is intended that teachers would use the content and procedures provided in the research as they are. In this case, concrete directions, examples of materials, and methods of use should be specifically described in the research. Additionally, the research geared towards this purpose often uses terms such as "*standards* for or *dimensions* of teaching, or *qualities* or *competencies* of teachers" to suggest specific directions for practice by assuming that it is effective for teachers to pursue or follow as given (Barnett & Hodson, 2001, p. 428). Others called this an 'instrumental use of research' (Farley-Ripple et al., 2018; Nutley, et al., 2007; Weiss, 1977).

To increase the effect of research's instrumental use, studies can be conducted to develop a specific programme or guidance for real-world teaching, not in the form of a paper, so that teachers can directly apply it. This approach's advantage is that it can help directly and immediately change or improve classroom teaching. As a matter of fact, as teacher educators, we have also developed and distributed specific and practical teaching materials. However, it has been observed that there were very few cases of teachers actually using the provided materials as they were. Teachers were more likely to transform and modify the provided materials according to their educational beliefs and values, teaching purposes, teaching environments, students' interests and academic levels, and so on. In the case of research papers, even if specific directions and strategies were presented, the modified use of the content was both likely and plausible.

This study focused on the concept of 'transformation' because it is not expected that research papers can be directly and simply employed for improving and changing teaching practice in schools. This is because teaching practice is strongly based on context (Kaplan et al., 2020). For example, in one study aimed at improving students' academic achievements in undergraduate introductory biology courses (Cromley et al., 2020), when researchers compared the effect of interventions for 50 studies, they found that nine studies showed no significant effect size. Even in the remaining 41 studies that did demonstrate a significant effect size, the values varied from 0.20 to 0.66. Therefore, Kaplan et al. (2020) challenged the assumption that well-designed educational research could be uncritically generalised across different educational settings. Furthermore, Kaplan et al. (2020) emphasised that the role of educational context, such as class size, the characteristics of students or teachers, and the class's motivational climate, should not be ignored in evidence-based teaching.

Therefore, in this study, the transformation model is taken to be more suitable for understanding teachers' actual processes in terms of using research papers. The transformation model occupies the middle location on the continuum: the enlightenment model on one end and the engineering model on the other. In other words, teachers should first be able to apprehend the new knowledge, ideas, and insights suggested, and then appropriately

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modify them, thereby more fully utilising the content according to their specific educational purposes and contexts.

For the first step taken in the transformation model, because the research papers were written academically, it is necessary to focus on ways to help teachers understand and interpret the papers. Therefore, this study first explored what difficulties teachers had in reading and grasping papers, and then examined how such difficulties could be resolved.

The second step included teachers using and applying the papers they did understand for teaching science in the classroom. As mentioned earlier, the use of research is context-laden; thus, teachers need to adjust and modify the content according to their educational beliefs, teaching purposes and situations, and their students' characteristics, such as students' interests or academic levels. This application process could be divided into several sub-steps, such as proposing ideas by applying the papers, developing concrete teaching materials, implementing teaching in the classroom, and reflecting on the implementation practice to improve the application of research. This study attempted to analyse what points, exactly, needed to be considered for the practical use of papers in this process. One regrettable point to note was that the analysis of the implementation and reflection processes could not be conducted during the COVID-19 pandemic. This study focused on and analysed the characteristics that appeared in the process of suggesting ideas by applying the papers and developing teaching materials.

Scientific Creativity

Creativity has been emphasised as one of the major goals of science education. For instance, AAAS (the American Association for the Advancement of Science) noted that "science classroom[s] ought to be a place where creativity and invention… are recognized and encouraged" in Project 2021 (AAAS, 1990, p. 204). The NRC (National Research Council) claimed that scientific practices could help students recognise that "the work of scientists and engineers is a creative endeavour" (NRC, 2012, pp. 42–43). Furthermore, in the 'Korean Science Education Standards for the Next Generation (KSES)', the image of humanity pursued by future science education is described as "creative and cooperative people [being] equipped with scientific literacy because … the 21st century is changing into a society that values creativity for new change based on knowledge" (KOFAC, 2019, p. 9).

To teach creativity, one must first mention the domain dependency of creativity (Baer, 1996). That is, creativity, in science, has different characteristics from creativity in the artistic field (Wolpert, 1992). Accordingly, scientific creativity can be defined as thinking creatively, including doing so with scientific knowledge in the context of scientific inquiry (Park, 2004; Park, 2011b). Therefore, for scientific creativity, in the case of a creative task like 'propose ideas to use an ordinary battery for other purposes', new idea of using scientific knowledge related to the battery (e.g., 'by dropping a battery from a high place and measuring the falling time, the height can be obtained') or using the battery for scientific inquiry activities are encouraged (e.g., 'manganese dioxide inside [a] battery can be added to hydrogen peroxide to make oxygen gas').

What is more, when trying to suggest creative ideas, some students may be unfamiliar with creative thinking. Therefore, Park (2004) suggested that teachers should also provide specific guidance on how to think creatively when presenting creative tasks. Figure 1 is an example of a guide for students' creative thinking.

Figure 1
A Guide to Help Students Generate Creative Ideas

To suggest alternative uses of a battery, the following examples can help you think creatively.

Ex. 1. The external characteristics of the battery can be used. For example, because it has a round shape, you can use it instead of a wheel to reduce friction.

Ex. 2. The battery can be used after disassembling it. For instance, the carbon rod inside can be used as a conductor rod.

Ex. 3. A battery can be used for performing scientific inquiry. The manganese dioxide inside the battery, for example, can be added to hydrogen peroxide to make oxygen gas.

Ex. 4. Consider the battery just as a simple object. If you drop it from a high place and measure the falling time, you can calculate the height from which the battery was dropped.

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Teachers often think that teaching creativity is difficult. Moreover, some think that creative thinking is only necessary for gifted students. However, according to the viewpoint that creativity is a habit of thinking (Richards, 2007; Sternberg, 2007), the small but repetitive experiences of creative thinking introduced during ordinary science classes are sufficiently helpful in developing creativity. In fact, Kang et al. (2015) observed that it took only about 13 minutes for regular students to propose 90% of their ideas for a specific creative task and then, after 19 minutes, no additional ideas emerged. Of course, the time will vary depending on the students' level and the type of task, but it does suggest that creativity-oriented activities are possible using such a short time in class.

Research Methodology

General Background

This study was conducted in a course of the graduate school of education. Three physics teachers enrolled in this course participated, and their process of learning and utilising academic papers were analysed. This course took place over three weeks in January 2021. The course's goal was to understand scientific creativity and develop teachers' competency to utilise their understanding for improving their school science teaching. During the course, participants were asked to read research papers on scientific creativity and to conduct discussions to better understand the papers. Then, they developed actual teaching materials. Through this, 27 hours of recording data on teachers' activities and the results of teachers' activities were obtained. By analysing these, participants' difficulties and deficiencies in both understanding papers and developing teaching materials were identified; it was then analysed which activities or supports were helpful to address such challenges and to supplement deficiencies in developing teaching materials. Based on the results, the role of teacher educators in supporting science teachers to understand and use academic papers properly for science education in schools was discussed.

Participants

All three participants were contracted physics teachers and were also graduate students in university in Korea. Two were female, one was male, and their average teaching experience was about five and a half years. Before the course began, they all listened the course's purpose and agreed to record classes for research. It was also announced that, after the course ended, analysing the recordings would be conducted and the grades would be assigned so that using the recordings would not be disadvantageous to the students' course activities or grades. This research was confirmed by IRB (Institutional Review Board), a research ethics committee in university, that there were no ethical problems. Finally, all participants submitted a form consenting to the use of data obtained from them.

Instrument and Procedures

This course was an intensive course, that is, the class was held for a total of 45 hours for three weeks, three hours a day during the winter holiday. Due to the COVID-19 pandemic, the course was conducted as a real-time distance learning class via a video conferencing system. The course's aim was to enhance teachers' ability to utilise academic research papers for their own teaching of scientific creativity in classroom. The course process is summarised in Figure 2.

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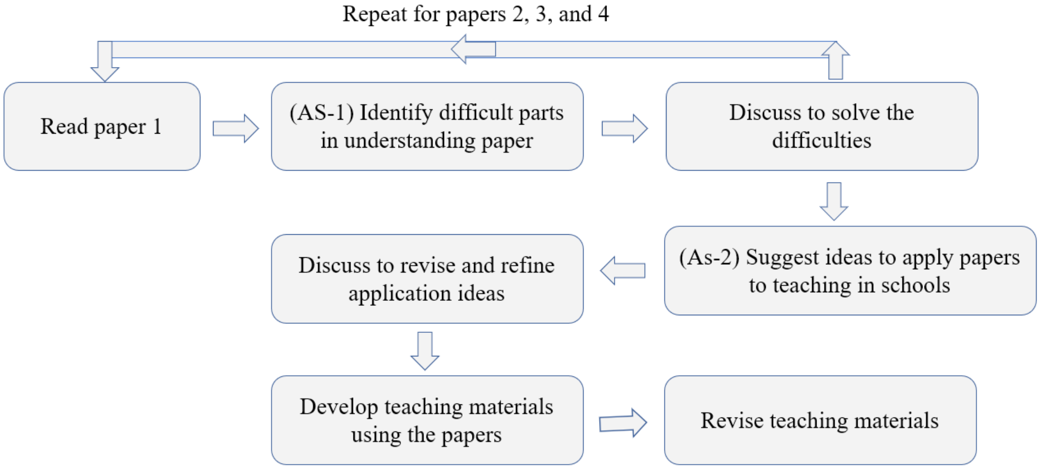
Figure 2
Course Process



First, they read and understood four research papers regarding scientific creativity as part of the assigned classwork. The four papers balanced theory and practice with two theoretical papers and two papers on practical application. Although there are many papers regarding this topic in English journals, papers written in Korean were chosen in this study because they were easier for participants to understand. In addition, by selecting the papers written by one of the authors of this paper, there was no difficulty in teaching the papers.

The first paper (Park, 2004) is about a scientific creativity model. The second paper (Park, 2011a) describes operational definitions for various scientific creativity elements. For example, fluency is defined as the number of ideas or products, flexibility as a number of different categories of ideas or products, originality as new ideas or products that others do not suggest or make, and so on. The third paper (Park & Kim, 2013) presents the analysis results on the types and characteristics of the developed various activities for scientific creativity. The last paper (Jee & Park, 2014) reports the positive application effect of elementary school students on improving science creativity by engaging in creative science activities with their parents at home.

Second, while reading the papers, teachers wrote down the parts of the papers they found difficult to grasp, as well as the additional information and discussions needed to understand the papers on the 'Activity Sheet 1 (AS-1)' (see Table 1). Because they read four papers, each teacher wrote four AS-1s; therefore, a total of twelve AS-1s were written by three teachers.

Table 1
The Questions on Activity Sheet 1 (AS-1)

No.	Question
Q1-1	What did you understand for the first time in the paper? What was difficult to understand in the paper?
Q1-2	What additional references and information do you need in connection with the paper or to understand the paper?
Q1-3	What else do you want to discuss about the paper?

The participants, as the third step, shared their completed AS-1s with one other and discussed what they had written with others and a professor (who was one of the authors). During the discussion, additional information or related papers were searched for on the Internet and subsequently learned.

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Next, regarding the second through fourth papers, the above process was repeated, from the first through third steps. In this process, the number of questions for each paper was about 20 ~ 30 (23.9 in average), and discussion time for each paper was 2 ~ 9 hours (5.8 hours in average). The teachers' questions were not answered directly by the professor but, rather, the professor gave them all time to discuss among themselves, even allowing them to search for related papers or information on the Internet. Therefore, a considerable amount of time was needed to understand each paper.

Fifth, after engaging in discussions aimed at understanding of the four papers, an 'Activity Sheet 2 (AS-2)' was written to propose basic ideas for applying what they have learned to their actual teaching contexts (Table 2). Additionally, participants also wrote about which aspects should be considered to clarify and articulate their own ideas. An AS-2 was written by each teacher, so there was a total of four AS-2s. Afterward, the ideas were shared and revised through discussions.

Table 2
The Questions on Activity Sheet 2 (AS-2)

No.	Questions
Q2-1	What are the basic ideas for applying these four papers in your science classroom?
Q2-2	To what extent is an effect expected if you apply these papers to your class according to your idea? What kinds of difficulty might there be when applying them in your classroom? What conditions or supports are needed for an effective application?
Q2-3	When you try to apply these papers in your classroom, what other information, papers, references, or additional interpretations do you need?
Q2-4	What else do you want to discuss about applying these papers in your classroom?

Finally, each teacher developed concrete teaching materials using the ideas proposed in the fifth step. The teaching materials included teaching plans, students' activity sheets, and teacher's guides for practical use. The topics included in the newly developed teaching materials were as follows: (1) 'Creative scientific activities with parents', (2) 'Creativity in conducting science experiments', and (3) 'Creativity in science learning in the classroom'. These materials were also shared with one other and subsequently revised through discussions.

Data Collection and Analysis

Main data were obtained from the AS-1s, the AS-2s, discussions based on the AS-1s and AS-2s, teaching materials developed for scientific creativity in schools, and discussions aimed at modifying and revising the teaching materials.

First, there was a total of 12 AS-1s (four AS-1s written by three teachers each), and 23 hours of recorded discussions on the AS-1s. All recordings were transcribed. Because of a technical problem during the recording process, about six hours could not be transcribed; thus, a total of 17 hours of recordings were analysed. In analysing these data, researchers identified teachers' difficulties in understanding the papers and explored what kinds of help were needed to resolve these challenges.

Next, there was a total of three AS-2s (one AS-1 written by three teachers each), and the transcribed data from six hours of recordings of the discussions on the AS-2s. From this data, researchers evaluated the basic ideas for applying the content of the research papers to science teaching in the classroom and analysed the aspects that needed to be considered to clarify and articulate ideas.

Third, teaching materials developed by applying papers and the recordings of the discussions were analysed. Data for the analysis were comprised of the three teaching materials developed by each of the three teachers and the recording transcriptions for the six-hour discussions.

Finally, based on the results obtained in the above process, researchers discussed what role teacher educators should play to link academic research and teaching practice, that is, research-based teaching.

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Although the number of participants, which was three, was small, the amount of data to be analysed was sufficiently large. In total, there were 15 activity sheets (12 AS-1s and three AS-2s), three developed teaching materials, and a total of 29 hours of recordings (17 hours for the AS-1, six hours for the AS-2, and six hours for the discussions about developing and revising teaching materials).

Research Results

The Process of Teachers' Understanding Academic Papers

Difficulties in Understanding the Academic Papers

By analysing the AS-1 content and their discussions, difficult aspects encountered when teachers tried to understand the papers could be classified into two categories (see Table 3).

Table 3
Teachers' Difficulties in Understanding Academic Papers

Types of Difficulty		Examples
Academic terms, explanations, and content	Terms	Internal consistency of scientific creativity; Convergent insight; Abductive thinking; ANOVA; Effect size; etc.
	Explanations	Scientific inquiry skills can affect scientific creativity; Unconventional thinking has common property with fluency or originality; etc.
	Cited content	SCAMPER (Eberle, 2008); A model of scientific creativity by Hu & Adey (2002); Creativity programs by Cropley (2003); etc.
Scientific Knowledge		Galileo's free falling thought experiment; Kekule's snake dream and Benzene molecule; etc.

First, teachers faced challenges in understanding professional academic terms, such as 'abductive thinking' (Park, 2011a, 2011b), and technical terms used in data analysis and interpretation like 'effect size'. In addition, it was also observed that they struggled to distinguish between terms, such as 'difference between unconventional thinking and originality'.

In addition to the terminologies, teachers faced obstacles when trying to understand the explanations presented in the papers. While grasping terms implies understanding a single concept, comprehending an explanation means to know the relationship among concepts. For example, apprehending the meaning of 'scientific inquiry skills affect scientific creativity' can be seen as being aware of the relationship between scientific inquiry skills and scientific creativity.

The above difficulties were described in the AS-1s, but additional obstacles were found during the discussion. For instance, regarding the explanation that 'science creativity is to think creatively, including scientific concepts during scientific inquiry activities', teachers initially said they understood it. However, when they were asked to explain what inquiry skills, scientific concepts, and creative thinking elements were included in a specific creativity task, they actually demonstrated a deficient understanding. The following is a summary extracted from the discussion about this.

[… using a cup containing water and a stick, teachers were asked to make many observations and observe what others have not seen]

Professor: Are scientific concepts included in this task? (fifth day (2), 17:14)

Teacher 3: I don't think there are no [specific] scientific concepts… (fifth day (2), 17:37)

Professor: Then, can this [observation] help [students] study the concept of refraction? (fifth day (2), 20:32)

Teacher 2: … yes (fifth day (2), 20:38)

Professor: So, then are other science concepts included [in these observational task]? (fifth day (2), 20:50)

Teacher 2: … reflection, … (fifth day (2), 22:26)

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What is more, the papers often cited other studies, but the explanations of the cited content were usually summarised, so there was a dearth of understanding about them. For example, in 'SCAMPER' (Eberle, 2008), 'Cropley's program' (Cropley, 2003), or the examples cited in other instruction materials for teaching creativity, teachers asked what those were.

Finally, the papers presented some examples of scientific creativity activities which included scientific content. Some teachers demonstrated little understanding of the science content itself. For instance, one paper explained that new ideas could be created from the perception of logical contradictions, and it also provided Galileo's thought experiment as an example (Park, 2004, 2011a, 2011b). In this particular case, some teachers revealed a lack of understanding about Galileo's story itself.

Activities to Help Teachers Understand the Papers

It can be said that various difficulties, which have been detailed in Table 3, were likely to be expected. However, this specific set of data can function as a starting point for ascertaining how an academic paper should be transformed for teachers to understand it. For example, the following operational definition for abstract terms, such as 'unconventional thinking' (Park, 2011a, 2011b), was found to help science teachers understand: 'Unconventional thinking refers to thinking reversely or changing conditions, structure, or law'. This indicates that the paper needs to be modified to include operational definitions of the papers' academic terms. In addition, through the discussion process between a professor and participants, activities that were necessary to help teachers comprehend the papers were identified (see Table 4).

Table 4
Activities to Help Teachers Understand Academic Research Papers

Type	Activities to Understand the Papers
Suggesting interpretations	Using the operational definition of a term
	Generating specific examples of terms or explanations
	Explaining the similarity or difference among terms
Adding information	Searching for additional information on the cited content
Performing activities	Performing directly the activity examples provided in the paper

According to Table 4, providing specific examples that could clarify term and explanations were helpful. Figure 3 is an example which helped teachers understand what 'thinking reversely' means.

Figure 3
An Activity Example of 'Thinking Reversely'

- An LED can convert electric energy into light energy. Then do you think an LED can be used to generate electric energy using light?

- Observe it using a bright light of beam project (The photo indicates the observational method and result).

- Suggest other phenomena by which we can discover interesting results by thinking in reverse.

Third, explaining the differences among similar terms also helped teachers understand concepts more clearly. For example, for the phrases 'creative thinking' and 'creative output' (Park, 2011a), the following explanation was helpful: 'creative thinking' emphasises process, but 'creative output' corresponds to the result obtained through the creative thinking process.

Next, regarding the content cited in other papers, additional explanations or interpretations were required.

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For instance, the paper cited a study result that "The correlation between creativity by area was low at 0.37" to explain the domain dependency of creativity. Here, the following additional explanation was helpful: 'Low correlation means that creativity scores may not be high in the area of science, even if creativity scores are high in creativity area of language'.

In this process, it was helpful to actually do activities. The following is a summary of the activity that aided their understanding of the concept 'domain dependency of creativity'.

Professor: Describe the 'love' in different expressions. (third day (2), 39:49)

Teacher 1: Love is the sun, … Love is sunflower. (third day (2), 41:25)

Teacher 1: Love does not need words. (third day (2), 31:46)

[Teachers suggested three more expressions for 'love'.]

Professor: Then, your fluency score is six [because the fluency corresponds to the number of ideas]. … (third day (2), 41:51)

Professor: Now, let's go to scientific fluency. There is a thermometer, but instead of measuring the temperature, suggest alternative ideas for other experimental uses. (third day (2), 42:19)

Teacher 1: … it can be used to measure the length. … (third day (2), 42:25)

[The teacher 2 suggested two more ideas for the alternative use of the thermometer.]

Professor: … three [ideas]. [So the score of scientific fluency is three, it is different from the score of verbal fluency, six.]" (third day (2), 43:19)

Teacher 3: Therefore, [this means that] creativity depends on area. (third day (2), 45:31)

In fact, it is expected that teacher educators may routinely use some of the things in the table 4 in the course of teacher education. In that sense, the above comprehensive results obtained from teachers' actual learning process can be utilised to create practical guides for teachers to understand academic papers more easily, and to do so in a more systematic way. In other words, when there are specific papers that are considered useful and are also available in schools and, furthermore, if teacher educators want to transform papers so that teachers can grasp abstract academic studies, the activities in Table 4 can contribute quite strongly to this purpose.

The Process of Applying Papers to Teaching Practice

Proposing Ideas for Applying Papers to Science Teaching in Schools

In the AS-2s that suggested basic ideas for applying the papers on scientific creativity in the classroom, three teachers suggested a total of nine application ideas (see Table 5).

Table 5
Ideas for Applying Scientific Creativity to Science Teaching in Schools

Context	Ideas for Application
Classroom or laboratory teaching	- Conduct a weekly creativity activity (insert creativity activity into the regular lesson) in middle school science classes. - Conduct creativity activity every time when finishing a small unit, in high school physics classes. - Use a creativity activity task as a performance assessment. - Insert a small creativity activity into a high school experiment. - Develop and use a separate scientific creativity programme for seventh grade classes.
Club activity	- Develop and use a scientific creativity programme for club activities. - Test the level of scientific creativity of the students in the club. - Develop and use a creativity programme that students and their parents perform together in the club.
Family activity	- Develop and use a family creativity programme that family can perform at home.

After proposing ideas, each teacher selected one idea, shared ideas, and discussed to refine the ideas further. In the discussion, four aspects were considered in terms of revising and articulating ideas (see Table 6).

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Table 6
Considerations to Refine Ideas to Apply Scientific Creativity in Science Teaching in Schools

Consideration Aspect	Refined Ideas
The target and scale	- Small-scale scientific creative activities, which run for 20 minutes in one-hour classes, will be used in middle and high school classes. These will be conducted about 15 times a year. - The family programme will be applied to 30 parents at once (for 40 minutes) per week for four weeks.
Development method	- Existing materials for teaching scientific creativity will be used. - I will develop the materials myself.
Expected difficulties	- I expect that it is difficult to develop materials independently, so I need the help of other teachers. However, they may be unfamiliar with scientific creativity. - I am worried that students will not participate actively in creativity tasks.
Materials to be developed	- I will develop 20-minute creativity activities that can be used in my regular one-hour class. - I will develop and insert one or two steps of creativity activity into an existing experimental procedure.

According to Table 6, teachers were interested in various practical aspects in refining the suggested ideas. For example, they tried to decide how many minutes of activity they should do and for how many students. This was because they considered it as necessary to determine the level and scale of the activity when applying the idea in a practical teaching situation. In particular, considering how many activities could be applied per year is important in that they tried to use them for changing and improving their regular science teaching, rather than as a trial application once or twice.

Regarding teaching material development, teachers suggested that it is necessary not only to utilise existing materials pertaining to teaching scientific creativity but also to develop by themselves and to exercise them repeatedly to become familiar with them. However, they also said that, because it is not easy to do this alone, it would be necessary to do it with other teachers. Thus, in order to substantially change or improve science education, cooperative efforts of science education community are required.

Teacher 1: … I think it would be best to do [creativity activities] regularly to adapt it to [scientific creativity] … (twelfth day, 08:30).

Professor: … alone? or with whom? (twelfth day, 08:45).

Teacher 1: … with other teachers in school … (twelfth day, 09:00).

Teacher 1: … [then] I think I can receive feedback [from other teachers]. (twelfth day, 09:14).

Teacher 2: If you ask [other teachers] to do it to get used to it, will [they] try it? (twelfth day, 09:54)

Teacher 3: Maybe … (twelfth day, 09:57)

Finally, teachers discussed what specific materials needed to be developed. For example, rather than teaching creativity as a separate activity during independent time, teachers planned to insert creativity activities into their regular science classes on classroom or laboratory according to the science curriculum. This idea was a necessary aspect for teachers to properly utilise the content of the papers according to the teacher's teaching goals, and in line with their teaching environments.

Developing Materials for Teaching Scientific Creativity

Among the ideas listed in Table 6, three were chosen to develop creative activity materials: adding one or two steps of small creativity activities into the existing inquiry experiment in textbook, inserting one or two small creativity activities (about 10- to 20-minute activities) into regular classroom instruction, and developing creative activities that can be conducted at home with parents.

After developing these three teaching materials, the teachers shared them, identified shortcomings, and discussed ways to supplement and improve them. Table 7 summarises the modifications and supplements produced in this process.

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First, when developing teaching materials, some teachers did not directly perform creative activities included in the materials. For example, one teacher designed a task to ask students to propose 'many and various ideas that others had not thought of'. However, when the professor asked him to perform it himself, he realised that the activity level was higher than he had expected. Therefore, it was observed that performing creativity activities directly, themselves, played an important role in checking on the time required, students' interest, difficulty level, and what ideas could actually be proposed.

Table 7
Activities to Revise and Supplement the Developed Teaching Materials

Focus	Activities for Revision
Creativity	- To perform creativity activity directly. - To develop and add guidelines about how to think creatively.
Scientific knowledge	- To scrutinize scientific experiments for deeper understanding.
Coordination between creativity and science content	- To link the developed scientific creativity activity to the science content being taught. - To modify the creativity activity appropriately by considering the science content.
Learner	- To adjust the difficulty level according to learners' levels.

Next, in the early versions of certain materials, there were no guidelines for how to think regarding generating creative ideas. Rather, there was only a directive statement like 'Propose creative ideas.' As mentioned in the section of this paper on the theoretical background, specific guidance about how to think creatively is necessary for students because creativity activities may be unfamiliar to them.

Third, in articulating and supplementing materials for teaching scientific creativity, it was found that an understanding of not only creativity itself but also of scientific content was important. For instance, the experimental situation presented in the textbook was 'Shampoo comes out using pressure change'. And creativity task was 'Suggest the different variables that can possibly affect the experiment's result.' However, a teacher could not explain accurately how the pressure inside the shampoo container changed and, thus, shampoo came out. In this case, even though a teacher tried to suggest creative ideas, he or she failed to identify a range of variables, due to the lack of an accurate understanding of the experimental situation. As a result, the teacher recognised the developed creativity activity as inappropriate and eventually changed to another experimental topic. This means that, in order to utilise a pedagogical strategy properly, a basic understanding of the subject's content is a prerequisite.

Although understanding the creative and scientific content was sufficient, the fourth step was to connect the two meaningfully. Indeed, this was a vital aspect for revising and supplementing teaching materials. For example, when teaching 'static electricity', a teacher planned to add a creative activity asking students to 'Describe static electricity in the form of sentences or pictures, as many as possible (fluency), simply and clearly (simplicity), and accurately (elaboration)'. In this case, the teacher introduced this activity at the beginning of class before students learned the basic and various characteristics of static electricity. However, it was later judged inappropriate. That is, it was difficult for students to suggest creative ideas related to static electricity because they had not yet learned the basic concept of static electricity.

Fifth, when linking creative activities to the scientific content, it was necessary to select a suitable activity that directly related to the content. For example, some of the developed material included an activity with the following instruction: 'Observe lightening of a neon lamp by touching it to an electrified plastic rod [that has been] rubbed with fur leather'. In this activity, the teacher inserted a creative activity by asking students, 'Suggest many and different variables which can affect lightening of the neon lamp'. However, because this experimental situation was too simple, it was difficult to suggest various factors that may have affected the lightening of the neon lamp.

Finally, it is also important to revise and supplement materials according to the level of subjects who will carry out the creativity activities. For instance, in the materials designed to guide parents for the creative activity programmes, there were academic terms that were expected to be difficult for parents to understand, such as 'organized system' and 'similarity inference'. Thus, teachers modified these expressions.

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Discussion

The first and the second research goals were to understand more deeply the process of teachers understanding academic research papers and then applying them to their teaching in the classroom. The results are summarised in Figure 4.

Figure 4
Transformation Process of Academic Research Papers

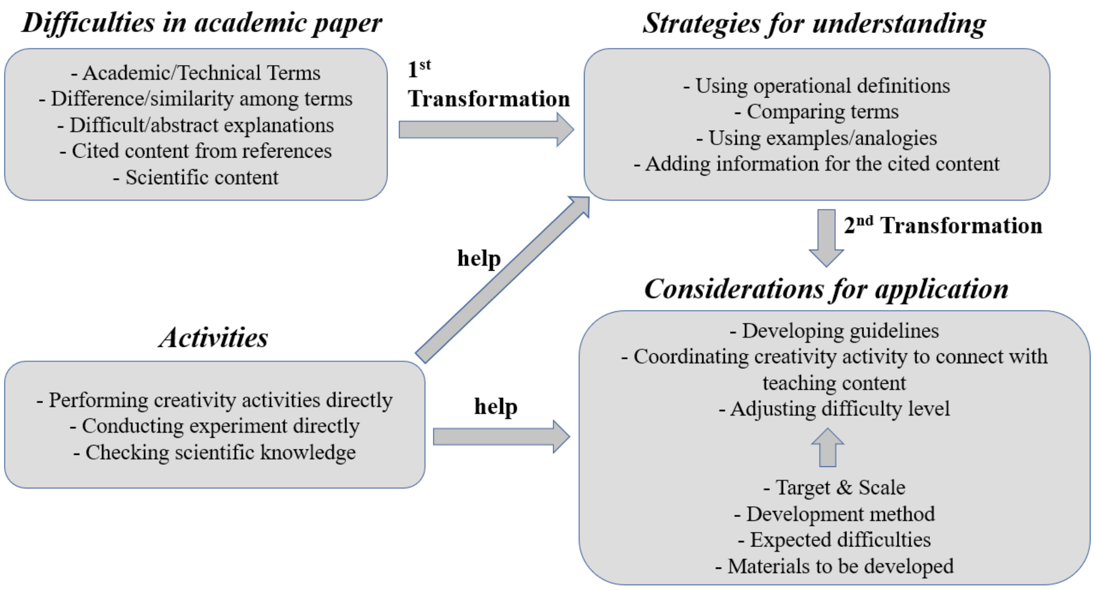

Figure 4 indicates what was the first transformation needed for teachers to understand academic research papers. That is, because teachers had difficulties understanding the academic and technical terms used in the papers, the differences and similarities among terms, the harder and more abstract explanations, cited contents, and scientific contents themselves, the first transformation of the paper was necessary to address these challenges. This was accomplished by defining terms operationally, comparing the terms, suggesting examples or analogies, and adding information related to the cited contents.

These findings may not be altogether new results. However, what should be mentioned here is that both the above difficulties and difficulty resolution processes were extracted through active participation and discussion by teachers. In other words, it was extracted from the teacher's actual learning process rather than learning theories or logical reasoning. Therefore, these practical outcomes are important when presenting papers to teachers in a more systematic way. For example, among papers published in professional academic journals, there are a lot of papers deemed likely to contribute to changes and improvements in teacher practice. In this case, we would like to propose the publication of a '*Teacher's Magazine*', which would be comprised of transformed papers, which would be more teacher-friendly, by using this study's results. In fact, the process and effort required to provide academic papers to teachers in a systematic way are not by any means routine. Therefore, the next study can be recommended to develop practical ways that can be systematically provided by transforming academic papers for teachers.

Secondly, Figure 4 suggests which aspects need to be considered when teachers propose ideas for using academic papers in their teaching practices and when they try to develop actual teaching materials based on such ideas. That is, academic research papers need to be transformed by developing guidelines to help students think about or engage in learning activities in class, coordinating the content or activities presented in the paper with the teaching contents according to the regular science curriculum, and adjusting the difficulty level by considering students' interests or cognitive levels. In this process, that of the second transformation, it was also found that various practical aspects should be considered. That is, to develop teaching materials using academic papers, it would be necessary to consider the grade level and number of students to apply the materials, the number of times

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per year required for application, methods for how to develop materials, difficulties expected to be encountered when applying the materials, and the types of materials to be developed in detail.

Additionally, it is worth mentioning that it is important for teachers to perform actual activities directly in the process of transformation. In other words, the activities, such as directly performing creative activities or scientific inquiry activities presented in the papers, or directly checking textbook content and conducting experimental activities in textbooks, take up an important role in understanding or utilising the papers.

This study focused on the transformation of two stages in order for academic papers to be used in teachers' instructional practices. It is expected that this transformation process can help the academic papers be linked to educational practice. In relation to the third research goals, we need to carefully consider the role of the teacher educator as a 'research translator' (Hirschkorn & Geelan, 2008) or as 'knowledge brokers' (Meyer, 2010) in this process. That is, as Hirschkorn and Geelan (2008) suggested, a 'research translator' would be someone who can interpret and translate research findings in such a way that science teachers would find them comprehensible, plausible, and potentially fruitful. Meyer (2010, p. 118) defined 'knowledge brokers' as "people whose job it is to move knowledge around and create connections between researchers and their various audiences".

Rather than separate out independent persons or institutions for filling this role — that of the research translator — this study would like to suggest that teacher educators, science education associations, and/or science teachers themselves can serve as these research translators, thus connecting academic papers with actual teaching practice in the classroom. Members of 'The Science Education Association', especially, can transform academic research papers into teacher-friendly forms, contribute to the publication of a '*Teacher's Magazine*', and thus serve as research translators. Finally, when individual teacher educators develop teacher training programmes using academic papers, it is believed that this result can also be of great help.

Conclusions and Implications

As a science teacher, it has been emphasised that it is important for teachers to understand students' learning processes, such as what students' preconceptions are, what difficulties do they have in understanding concepts or in conducting scientific inquiries, what students' interests and motivations are, and so on. Likewise, as a science teacher educator, it is also vital to understand the process of science teachers learning about the educational theories or research results, and then using them for their own teaching practice in the classroom.

Taking up this point of view, this study first revealed what difficulties science teachers have in reading and understanding academic papers. Next, this study analysed how such challenges can be resolved. Based on this analysis, it was confirmed that transformation of academic papers from an abstract state to a concrete state was necessary.

Simply understanding an academic paper does not mean it can be automatically used for in the classroom. Therefore, secondly, this study also identified what needs to be considered when suggesting ideas for actually using the papers in their instructional practices. Next, this study examined the process of developing specific teaching materials based on these ideas. In this process, it was also found that various practical and specific factors involved in a real context of teaching must be considered to use abstract academic papers effectively in the classroom. In other words, the transformation of academic papers could be seen as a change from the state of 'generality' to the state of 'locality'. In fact, it is indeed the case that educational researchers focused their attention mainly on research that looked for general characteristics from individual and specific cases. However, it is also necessary to pay attention to the path going in the opposite direction, that is, on the translating from general theory to specific cases. This study is valuable in that it provides information on this opposite direction. Moreover, because the results of this study were extracted from the actual teacher's activities, it is expected to directly help develop the teachers' expertise.

However, this research also has some limitations. Although the amount of data was large, the number of teachers who provided data was not entirely sufficient. In addition, despite it was attempted to generalise the results obtained by this study, the outcomes are limited to a small number of specific papers. Therefore, this research team intends to expand the research method of this study to include other subjects and teachers. For example, there are many voluntary groups of teachers who strive to develop their educational expertise so that they can improve their instructional practices. In making these efforts, teachers often face problems or dilemmas that impede more meaningful and efficient teaching. To solve these problems and resolved these dilemmas, it plans to study additional ways to use academic research papers by transforming them into teacher-friendly formats. Of course, it is not easy

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to predict whether the use of academic papers will help teachers solve problems directly, practically, and effectively, but these efforts can strongly contribute none the less to narrowing the gap between research and practice.

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Declaration of Interest

The authors declare no competing interest

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