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SCIENCE TEACHERS' THEORY-BASED TEACHING: CONNECTING A LEARNING CYCLE MODEL TO A LESSON PLAN

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Abstract. *This research examined theory-based teaching processes of science teachers to understand the mechanism by which theory and practice were connected. Four science teachers desgined lesson plans by applying the empirical-abductive learning cycle (EALC) model and modified lesson plans through a collaborative interview with the researcher. Data were obtained from lesson plans and interviews. Using the constant comparison method with open coding, data were analyzed to find out obstacles or facilitators acted in the process of applying the EALC model to design lesson plans and reveal the path through which theory and practice were connected. As a result, it was found that perceptive prejudice about the role and necessity of the EALC model was the main obstacle. The collaboration process helped teachers understand the EALC model clearly and deeply. The development of this cognitive understanding changed their prejudice about the EALC model and led them to reflect their teaching practices with the eyes of theory. Through this process, a separated state between theory and practice was developed to a connected state. With the belief that it is a good starting point for coordination between theory and practice, further studies are proposed.*

Keywords: *abductive thinking, lesson plan, learning cycle, hypothesis generation, theory-based teaching*

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Introduction

Theory-based or knowledge-based teaching is an effective approach to achieve quality teaching in science class. Therefore, science teachers must be equipped with not only a solid theoretical background of scientific knowledge, but also a thorough understanding of educational knowledge such as educational principles, learning theories, effective teaching strategies, school curriculum, and students' learning processes. They should also be able to utilize and apply these understandings of educational knowledge to their actual teaching practice in schools. That is, an essential component of quality teacher is the competency to connect theory to practice by applying educational knowledge to classroom teaching.

When defining the concept of pedagogical content knowledge (PCK) introduced by Shulman (1986) as a fundamental element of teachers' knowledge base, many educators have also emphasized the importance of its practical aspect, that is, teaching practice. For example, according to a hexagonal PCK model consisting of four types of knowledge (knowledge of curriculum, students' learning, instructional strategies, and assessment), teacher efficacy, and orientation to teaching science (Park & Oliver, 2008), 'PCK understanding and enactment' is positioned at the core of the model. That is, one of the main features of this model is that knowledge (understanding) and practice (enactment) are connected at the same level.

In the first PCK summit held in 2012 to reach an agreement on the concept of PCK, participants developed a new PCK model representing the relationship from 'teacher professional knowledge bases' to 'student outcomes' (Gess-Newsome, 2015, p. 30). In this model, 'PCK&S (PCK and Skill)' was included to emphasize the importance of the act of teaching along with knowledge. The reason why PCK&S was needed was explained as "teacher knows something does not mean it would be translated into practice" (Gess-Newsome, 2015, p. 37).

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In the second PCK summit held in 2016, participants developed a refined consensus model of PCK consisting of three main components: cPCK (collective PCK), pPCK (personal PCK), and ePCK (enacted PCK) (Carlson et al., 2019, p. 126). Here, ePCK, "the specific knowledge and skills utilized by individual teacher" (Carlson et al., 2019, p. 128), was introduced to stress teacher's actions drawn from his/her knowledge in a specific teaching situation in classroom (Carlson et al., 2019, p. 129). That is, ePCK implies the theory or knowledge connected with practice of teachers.

However, in the actual educational context, it is not difficult to see the state in which theory and practice are separated. That is, the educational knowledge that teachers have learned in college or in-service programs is not actively or effectively utilized in actual teaching in schools (e.g., Beach et al., 2014; Dewey, 1904; Korthagen, 2007; Park et al., 2016). For example, Dewey (1904) noted that student teachers did not use principles of education when they adjusted their teaching methods. Gess-Newsome (2015) mentioned that teachers were not convinced that academic knowledge of teaching was beneficial for their actual teaching. In fact, many teachers thought that the place where they really learned to become a teacher was the school that they taught rather than the university that they attended (Beach et al., 2014; Hoban, 2002, p. 113).

According to Lortie's estimate, students usually spend 13,000 hours in direct contact with teachers from a very close distance during school days (Lortie, 2002, p. 61). Such long and impressive experiences can give a great influence on shaping what teaching is. Although teachers have learned pedagogical theories in college, their educational principles and teaching methods are mainly determined by their educational experiences when they were students (Stofflett & Stoddart, 1994). Park et al. (2016) found that only 24% of educational theories and teaching strategies that science teachers said they knew were used in their school teaching.

The phenomenon that educational knowledge has too little effect on changing and improving teachers' daily teaching is called a gap between theory and practice (Cheng et al., 2010; De Corte, 2000; Korthagen & Kessels, 1999; Korthagen, 2007; Ribaeus et al., 2020). Since this gap has a long history in education (Korthagen, 2007; Lohmander, 2015), many educators have emphasized that closing this gap is one of the long-standing educational problems that need to be solved (Van de Ven & Johnson, 2006; Zeichner, 2010).

To narrow this gap, various causes of the gap have been examined and proposed. For instance, Korthagen and Kessles (1999) have proposed three major causes based on cognitive psychology. First, as mentioned earlier, pre-service teachers' preconceptions about teaching and learning formed from a traditional educational perspective when they were students could not be changed easily. Second, because of the lack of pre-service teachers' personal interest in teaching and the lack of experience in encountering practical problems in a school situation, new educational theories could not motivate them or be taken meaningfully. Third, since theory is usually abstract, systematized, and general knowledge, it does not give a quick or concrete guidance that teachers want in a complex situation of teaching.

Regarding the third cause mentioned by Korthagen and Kessels (1999), many other researchers have also pointed out that the features of theory can cause the gap. That is, there have been criticisms that educational theories are too abstract and general (Hiebert et al., 2002; Park et al., 2016) or are irrelevant to everyday teaching (De Corte, 2000). In addition, they could not provide concrete or teacher-friendly guidelines (Berry & Milroy, 2002, pp. 200-201). Therefore, they are not coordinated with practice in a relevant or meaningful way (Wren & Wren, 2009).

Because of the criticism of the limited role of theory, many researchers have been interested in practice or practical knowledge to narrow this gap (Ball & Forzani, 2009; Biza et al., 2015; Korthagen 2007; Lampert, 2010; Van Driel et al., 2001). For example, Ball and Forzani (2009) have asserted that teacher education program should be shifted from what teachers know to what teachers do. And Biza et al. (2015) have used a practice-based teaching method using fictional tasks designed based on realistic classroom scenarios in pre-service teacher education.

However, criticism about theory does not mean that educational knowledge has no role in actual teaching in schools. In fact, practical experience alone cannot provide teachers with the solution to close the gap between theory and practice. Rather, it has been emphasized that teachers should have strong theories for professional and high-quality teaching (Androusou & Tsfaos, 2018). For example, Hascher et al. (2004, p. 624) have asserted that "becoming a good teacher requires not only practice but professional learning environments which also foster advanced theoretical knowledge." Lohmander (2015) has also claimed that, to narrow the gap, university-based learning (theoretical knowledge) is necessary which can be linked to workplace-based learning (practical knowledge formed through practice).

Therefore, this research adopted the view of Lunenberg et al. (2007) that theory requires practice and vice

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versa. Although theory and practice have different features from an ontological and epistemological point of view, "(it is not that) they stand in opposition or they substitute for each other; rather, they complement one another" (Van de Ven & Johnson, 2006, p. 803). Theory and practice are not in an 'either/or' relationship, but in a 'both/also' relationship (Zeichner, 2010). Therefore, selecting a theory that is considered proper and using it in actual teaching situation effectively for students' learning goals is thoroughly meaningful. This view is different from the naive model of 'application of theory' which assumes that teachers who have learned theory well are expected to use and apply the theory for their actual teaching skillfully (Zeichner, 2010). Rather, this research is focused on understanding the process and mechanism by which theory is connected to practice more in detail.

With this background, this research tried to identify conditions required for the theory to be connected to practice and explain how such connections could occur. That is, this research first attempted to extract what difficulties science teachers faced when they tried to understand and utilize educational theory. The reason why this research was focused on teachers' difficulties was that it could act as a major obstacle to the connection between theory and practice. This research also tried to find factors contributing to solving these difficulties and explain the process by which the relationship between theory and practice changed. It is believed that the information obtained from this research can contribute to narrowing the gap between theory and practice.

This research chose a 'learning cycle' model as an educational theory. This model is a well-known three-stage instruction model (Karplus, 1980). It has been expanded to the revised model of 5E (Bybee et al., 2006) or 7E (Eisenkraft, 2003). The learning cycle model has three types: descriptive, empirical-abductive, and hypothetical-deductive learning (Lawson et al., 1989; Lawson, 1995). This research selected an 'empirical-abductive learning cycle (EALC)' focusing on students' proposal of scientific hypotheses. The reason for choosing EALC is that improving hypothesis generation ability has been emphasized as an important aspect in scientific inquiry (AAAS, 1967; Karupaiah & Daniel, 2021; Lawson, 1995; MEST, 2009). If science teacher can use the EALC model properly to teach students to propose hypotheses in inquiry activities, this can be seen as a successful example of linking theory to practice.

This research focused on designing a lesson plan among various types of teaching practice. Designing lesson plan is a systematic, purposeful, and important action for teaching, along with the implementation of it in the classroom. According to Danielson's (2007) 'teaching framework' consisting of 22 components in four domains, one of the domains is 'planning and preparation' (the other three domains are 'the classroom environment', 'instruction' and 'professional responsibilities'), which includes 'designing coherent instruction' component. In the self-assessment instrument for science teacher competency developed by Kang et al. (2020), 17 elements among total 54 elements were included in a category of 'Science Lesson Preparation Competency'. Jacobs et al. (2008) have developed a 'Science Lesson Plan Analysis Instrument' consisting of 21 items, including 'goal orientation', 'students' participation', 'appropriate use of technology', and so on. As such, designing lesson plan can be seen as a fundamental element in teaching practice.

Research Questions

This study set the following research questions to understand how theory (EALC: empirical-abductive learning cycle) could be connected to practice (designing a lesson plan):

1) What difficulties do science teachers face when applying EALC model to design a lesson plan?
2) How and through what process does theory connect to practice by solving such difficulties?

Research Background

Theory-Based Teaching

In this research, the term 'theory' refers to educational knowledge such as educational principles and theories, instructional models, teaching strategies, and knowledge of curriculum and learners. This term is used to represent academic knowledge taught and studied in universities (Zeichner, 2010), which is distinct from practical knowledge of teaching formed through practice and reflection of teaching (Van Driel et al., 2001) or informal knowledge consisting of personal beliefs, assumptions, and specific know-hows about teaching (Deng, 2004).

Teaching can be defined as a set of purposeful and deliberate teacher's actions for helping students achieve learning goals in a classroom context (Gess-Newsome et al., 2019). Thus, a theory-based teaching means design-

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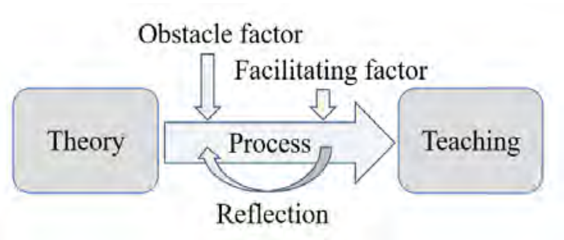
ing, implementing, and evaluating teacher's teaching actions for student's learning using educational knowledge in a systematic and conscious manner.

Researchers have provided evidence that theory is closely associated with teaching practice. According to Stofflett and Stoddart (1994), a group of pre-service teachers who learned content knowledge by conceptual change pedagogy showed higher use of it in teaching practice (designing lesson plans) than a control group. Stender et al. (2017) confirmed that everyday and routine teaching practice, called teaching script, was formed through the transformation of content-specific professional knowledge consisting of knowledge of the science curriculum, students' understanding of science, instructional strategies, and assessment in science (Magnusson et al., 1999). In another research (Gess-Newsome et al., 2019), teachers who participated in professional development programs showed an increased understanding of pedagogical knowledge (including general pedagogical knowledge and PCK), and at the same time, the quality of educational practice was improved when video-recorded classroom teaching was assessed using the Reformed Teaching Observation Protocol (RTOP), an observational instrument for analyzing classes (Sawada et al., 2002).

The above research showed that teaching practice could be improved by using theories. However, these results cannot be fully understood by a simple 'theory application' model which assumes that if a teacher can learn and understand educational theories well, then the teacher can apply such theories to their actual teaching practice efficiently (Zeichner, 2010). Wallace and Louden (1992, p. 517) have also criticized the assumption that "teaching is a matter of applying a set of generalized skills to given situations and that the role of teacher is to simply choose which skills to apply". Since simple 'theory application' model does not provide a sufficient explanation for the mechanism of how theory is connected to practice, more detailed explanations are required for what factors or conditions play an important role and what processes occur between theory and practice. Thus, the main objective of this research was to clarify the intermediate process between theory and practice as shown in Figure 1.

Figure 1
Theory-Based Teaching



In the 'theory-based teaching' model, various obstacle or facilitator factors are expected to play a role in the process of connecting theory with practice. And there may be specific paths from theory to practice. Therefore, this research first attempted to find out what difficulties interfered with the path from theory to practice by analyzing the process of teachers' understanding and applying theories. The process of solving these difficulties was then investigated. Results of this research are expected to provide a detailed information about the mechanism by which theory and practice are connected.

Empirical-Abductive Learning Cycle (EALC)

A learning cycle (LC) model was proposed by Karplus and Thier (1967) based on the Piagetian cognitive developmental theory and constructivist view of learning. This model consists of three phases: exploration, concept invention, and concept application. In the exploration phase, students conduct inquiry activities such as observing, measuring, suggesting hypothesis, designing experimental procedure, testing hypothesis, analyzing data. In the concept invention phase, new term is invented or introduced to understand and explain the inquiry results. In the concept application phase, students expand their understanding of concept invented in the second phase by applying it to different situations (Abraham, 2005; Marek et al., 1990).

The initial model of LC was further developed to inquiry-based model and subdivided into three types according to three types of scientific thinking: descriptive, empirical-abductive, and hypothesis-deductive LC (Lawson,

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1995). In the descriptive LC, scientific thinking of induction plays a main role in finding regular patterns from observational or measurement data, and a new concept is introduced or invented to describe regular patterns (Table 1). In the empirical-abductive LC, abductive thinking is used to generate scientific hypothesis to explain the novel observation. Here, the term 'empirical' refers to experience of novel phenomenon. In the hypothetical-deductive LC, using deductive thinking, students design experimental procedure to test the hypothesis and evaluate the hypothesis by comparing the hypothesis with experimental results.

These three types of LC can be utilized in different inquiry situations. Descriptive LC is appropriate for a situation in which various data are collected by changing variables or conditions. However, in the case of empirical-abductive LC, many and various data are not necessarily required. Rather, only one or two observations or data can be enough if they are curious or novel that cannot be explained by (student's) existing theories. If several competing claims are suggested to explain the scientific phenomena, hypothetical-deductive LC is useful to judge which claim is the most plausible as scientific knowledge.

Table 1
Main Features of Three Types of Learning Cycle (LC)

LC	Major Activities and Main Scientific Thinking
Descriptive LC	- collecting many data through observation or measurement - find a pattern or regularity from data using inductive thinking
Empirical-Abductive LC	- observe novel phenomenon which cannot be explained by existing theories - suggest hypothesis to explain the phenomenon using abductive thinking
Hypothetical-Deductive LC	- design experimental procedure to test hypothesis - evaluate the hypothesis based on the experimental results using deductive thinking

This research selected empirical-abductive learning cycle (EALC) as an instruction model for designing a lesson plan. In the EALC, curious and novel phenomenon and abductive thinking are the core. For example, if a student who knows that copper is not attracted to magnets and observes that a magnet falls very slowly inside a copper pipe which stands vertically, this observation is a strange and novel phenomenon to the student. In this case, student's tentative explanation of why magnet falls slowly corresponds to a hypothesis (Park, 2006).

Peirce (1998, p. 216), a philosopher of science, has asserted that explanatory hypothesis is formed by abduction. Hanson (1961, pp. 85-92) has also insisted that scientific new ideas are not sourced from induction or deduction, but from abduction. Lawson (1995, p. 7) has stated that abduction is a thinking that borrows ideas from other known situations similar to the current situation to explain the current situation.

Therefore, to think abductively, similarity-based reasoning is helpful (Park, 2006). In other words, in order to help students propose a hypothesis, it is recommended to guide students to find phenomena similar to novel phenomena or present similar phenomena directly and use them. For example, when students make sounds by rubbing their fingers on a wine glass, they can observe the interesting phenomenon that the wine glass makes a low sound when there is a lot of water. To suggest the hypothesis that can explain this interesting event, the teacher can provide another similar situation in which the thick guitar string makes a low sound. Then the students can recognize that these two phenomena are similar in that 'they are heavy' and 'they make a low sound'. Then, using the background knowledge that 'heavy materials are hard to vibrate', they can suggest the hypothesis that 'Just as a thick guitar string makes a low sound because it is heavy and difficult to vibrate, a wine glass with a lot of water makes a low sound because it is heavy and difficult to vibrate'.

Research Methodology

General Background

Four lower-secondary school teachers were asked to design lesson plans by applying the EALC model. Based on analysis results of those lesson plans, the researcher then prepared feedbacks to help those teachers revise their lesson plans. With the feedback, a researcher interviewed those teachers individually to extract teacher's difficulties

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in designing lesson plans and discussed with teachers how to solve those difficulties. This process was repeated until researchers were satisfied that the EALC model was well applied to lesson plans. Data were obtained from those lesson plans and interviews.

This research was approved by IRB (Institutional Review Board), a type of research ethics committee in a university, to confirm that this research had no ethical problems.

Participants

Four beginner science teachers in lower-secondary school voluntarily agreed to participate in this research (Table 2). Participants were restricted to beginner teachers who had less than five years of teaching experience. This is because it has reported that science teachers are usually very anxious to teach science in schools at this time (Jeon et al., 2009) and that the teaching experience of beginner teachers during this period could significantly affect their lifelong teaching styles (Stansbury & Zimmerman, 2000).

In a qualitative research, four participants are not considered as a small number. In this research, the amount of data obtained from the four participants was very large with 16 lesson plans and about 13.5 hours of recording files for 16 interviews using feedback. This study was conducted in 2021, and it took about 10 weeks to obtain data for the four teachers. Details of the data are described in the 'Data Analysis' section.

Table 2
Basic Information of the Participants

Teacher	Gender	Year of Teaching	Subject	Graduate Course
A	Male	4.3	Science	Master's degree
B	Female	1.3	Science	Master course
C	Male	0.3	Science	None
D	Female	0.3	Science	None

In Korea, because the job of being a teacher is one of the most preferred jobs, high-achieving upper-secondary school students want to enter a college of education in university and undergraduate students study very hard to pass the highly competitive national teacher's recruitment examination to become a science teacher. Since the learning cycle model is frequently presented in this examination, it is assumed that Korean science teachers have basic knowledge of the EALC model.

Process of Developing Lesson Plans Through Collaboration

The process of developing and revising lesson plans in Figure 2 was a 'collaborative' one because researcher (the first author) gave feedback and took interviews to help teachers recognize deficient aspects in their lesson plans and explore directions for improvement. In this process, the researcher suggested that revisions were necessary in the lesson plan without directly presenting specific solutions for the revision. The teacher made those revisions himself. The following is a sample of interview with feedback.

> ***Teacher A****: Students need to experience many things when applying the EALC model.*
> ***Researcher****: The amount of experience is not important in the EALC model. The key is to experience a phenomenon that students cannot explain the phenomenon and might be interested in explaining it. So, it would be better to have a fun and novel phenomenon if possible.*

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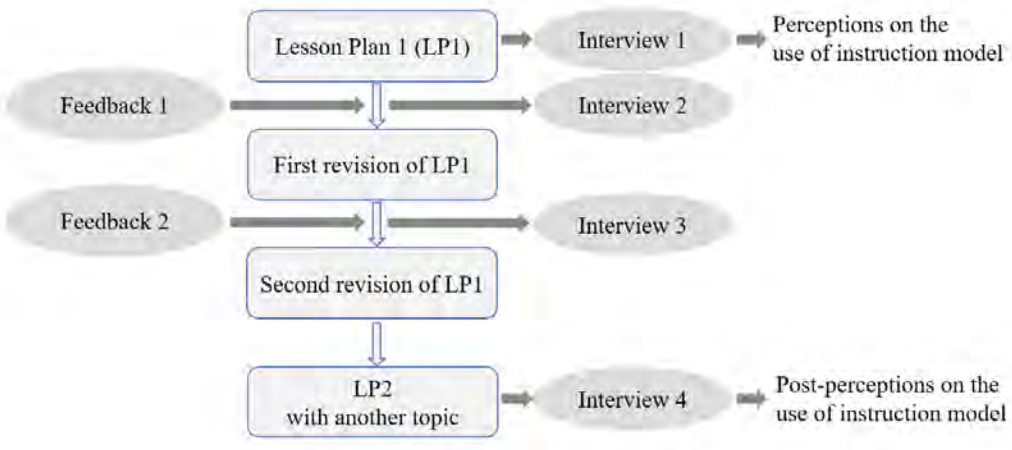
Figure 2
The Collaborative Lesson Plan Process



In Figure 2, the researcher first asked the teacher to design a lesson plan using an EALC model on the topic of 'Brightness of the lightbulb'. The teacher then designed a lesson plan with enough time and submitted lesson plan 1 (LP 1) to the researcher. A semi-structured interview 1 was then conducted for approximately 40 to 50 minutes to identify the teacher's perceptions of the use of instructional model and to extract difficulties when designing LP 1. Samples of questions used in interview 1 are shown in Table 3.

Table 3
Samples of Questions Used in Interview 1

No.	Question
1	Were there difficulties in designing the lesson plan?
2	Have you ever designed a lesson plan using a specific instructional model to prepare for a national teacher recruitment examination or in your college course?
3	Do you usually use a specific instructional model to teach science in school? What is the reason?
4	Do you think you need an instructional model? What is the reason?
5	What are the difficulties in designing the lesson plan using a specific instructional model?
6	What kind of help do you need to design a lesson plan using a specific instructional model?

Based on results of analysis of interview 1 and LP 1, researchers prepared feedback 1 to help the teacher improve his/her LP 1. The main purpose of Feedback 1 was to help the teacher recognize what revisions were necessary for more proper application of the EALC model in LP 1. In the course of feedback 1, interview 2 (approximately 30 to 70 minutes) was conducted to find directions to improve the LP 1.

Based on the feedback and interview, teachers revised their lesson plans and submitted their revised lesson plans online after a few days. The researcher then analyzed their revised lesson plans, prepared new feedback, and interviewed them again with feedback. In this process, some feedbacks were prepared in the form of reading materials as shown in Figure 3.

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Figure 3
An Example of Reading Material of Feedback

5. Abductive thinking
- For generating a hypothesis, it is necessary to present a curious event that students do not know the reason yet so that they have to think in their own way why such an event has occurred.
: in this case, abductive thinking is thinking to search for a possible explanation.
: abductive thinking is thinking that borrows a known explanation in a different (similar) situation.

(Example 1)
Observation: A small amount of current flows on a thin wire compared to a thick wire.
(Similar situation for) Abductive thinking: (because of more collision or frictions) It is more difficult for children to pass through a thin pipe in the playground.
Hypothesis: A small amount of current flows on a thin wire because a lot of electric currents collide with each other inside a thin wire.
…

…

When the lesson plan was determined to have been appropriately modified, the researcher (teacher educator) asked the teacher to develop a different lesson plan (LP 2) on a new topic that the teacher freely chose. After analyzing whether the application of the EALC model was appropriate in the LP 2, final interview 4 (approximately 40 to 50 minutes) was conducted to examine changes in teachers' perceptions and difficulties in designing a lesson plan using the EALC model.

The interview was conducted online using ZOOM, a video conference platform. It took about 10 weeks in 2021 to complete all these processes for four teachers. Interviews were all recorded using the ZOOM 'Record' function after obtaining consent from teachers.

Data Analysis

According to Figure 2, there were four lesson plans including revised ones and four interviews with feedback for each participant. Therefore, data obtained from four participants had a total of 16 lesson plans and recording files for a total of 16 interviews. Each size of the lesson plan was about 3 sheets of A4 paper. Feedback was composed of questions to be used for interviews or was developed in the format of reading materials to help teachers understand the EALC model. Each interview took about 30 to 90 minutes. The total interview time was 810 minutes (13.5 hours).

Data analysis was carried out to extract teachers' difficulties in the application process of the EALC model to design lesson plans and to identify changes in teachers' perceptions, understanding, and the use of the EALC model through collaboration with the researcher as a teacher educator.

Recording files were transcribed to texts using computer program. Researchers then corrected these transcripts to ensure precision by comparing them with the recording files. These transcripts were analyzed using a constant comparison method to perform open coding (Strauss & Corbin, 1998). That is, researchers continued to read the transcripts and lesson plans and repeated the process of identifying the meaning segments and giving the codes as descriptive names. After constructing codes from the transcripts and lesson plans, similar codes were grouped together and categorized as shown in Figure 4. In this process, discussions continued among researchers until consensus on the analysis results was reached.

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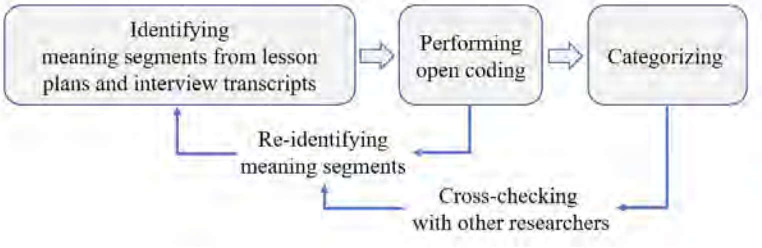
Figure 4
Process of Extracting Meanings from Data



Research Results

Difficulties in Applying the EALC Model to Design a Lesson Plan

When applying the EALC model to design a lesson plan, six difficulties in the following two areas were extracted: awareness of instruction model and understanding and application of EALC model or science knowledge (Table 4).

Table 4
Difficulties in Applying the EALC Model to Design Lesson Plans

Area		Difficulty
Awareness of instruction model		No awareness of the need for instruction model
		Misunderstanding about the role of the EALC model
Understanding and application	EALC model	Lack of understanding of the EALC model itself
		Using an inappropriate inquiry situation for the EALC model
		Missing scaffolding strategy to help the student think abductively
	Science knowledge	Lack of knowledge about scientific experiments

No Awareness of the Need for Instruction Model

As the first difficulty, some teachers perceived that instruction models were not necessary for their teaching in school. For example, teacher B said that there had been no difficulty for students to understand science contents even if she did not apply a specific instruction model. Teacher A also said that he did not use instruction models because these models were usually teacher-centered and too theoretical. During the interview, teacher A said:

> "The existing instruction models (in general) are focused on teachers anyway. So, the moment I apply the instruction model, it becomes a teacher-centered teaching. I can't use it because it doesn't fit the trend (nowadays, student-centered learning is being emphasized). … (moreover) The instruction models are … too theoretical. They are too huge (complex) strategies for the teacher to use it right now." (Interview 1, teacher A)

However, teachers C and D showed different perceptions of the instruction model. That is, teacher C said that it was necessary to learn the instruction model theoretically. Teacher D thought it would be good to follow the instruction model because the instruction model was systematic. Teacher D said:

> "If the teaching is guided well by the instruction model, I know that what the model pursues, such as (developing) creative thinking of the student, will work well." (Interview 1, teacher D)

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Here, the interesting thing was that teachers with short years of teaching experience (teachers C and D had 0.3 years of teaching, Table 2) generally showed positive perceptions about the use of the instruction model, while teachers with relatively long teaching experience showed negative perceptions (year of teaching: 1.3~4.3). This difference might be due to familiarity and mannerism of one's own teaching style. That is, it could be inferred that teachers who had more than one year of teacher experience had already become accustomed to their own routine teaching that they did not use specific instruction models.

Misunderstanding about the Role of the EALC Model

Second, some teachers misunderstood the role of the EALC model. For example, teacher A stated that the EALC model was similar to discovery learning and other instruction models for inquiry learning. Therefore, all methods for teaching inquiry were similar. Teacher A said:

> "… usually, the stage (of the instruction model) is 'the recognition of prior learning – experiment - introduction of concept from experiment - application of concept - summary'. … The EALC model is not much different from this." (Interview 1, teacher A)

All other teachers showed similar perception about the role of the EALC model. For example, teacher D stated that:

> "I can think of the steps and activities of other models, but I think these are similar to this (EALC). The order and the focus (of the instruction models) are little different, … the same goes for other models..." (Interview 2, teacher D)

Although some teachers thought that all experiments were similar in that students observed, collected, analyzed data, and drew conclusions using tables or graphs, the procedure or main activities of the scientific inquiry might differ depending on the purpose of the inquiry. In particular, school science often focuses on specific stages and inquiry skills rather than conducting the entire process from finding inquiry questions to drawing conclusions through experimental data. Therefore, the three types of LC models emphasize different purposes, different activities, and different use of scientific thinking, as explained in the theoretical background section.

That is, the EALC model focuses on observing new and novel phenomena that cannot be explained by student's existing theories. Therefore, to explain them, proposing new hypotheses using abductive thinking should be a main activity.

However, teachers showed a lack of understanding about the specific goal and role of EALC model. This leads to a difficulty in designing a differentiated lesson plan for inquiry activities that emphasize specific purposes, inquiry skills, and scientific thinking.

Lack of Understanding of the EALC Model Itself

Lack of understanding of the EALC model was found as the third difficulty. For example, teacher A confused abductive thinking, which was an essential part of the EALC model, with inductive thinking. The following is teacher A's thought:

> "To do EALC, students need to experience many things. In the textbook, students are asked to do an experiment with one light bulb first and then two, but for more experiences, three and four are required … Then students can propose hypothesis that 'the more (light bulbs) are connected, the darker the bulb becomes' by observing that light bulbs become darker when more bulbs are connected. But there are only two experiments, so there is not enough experience." (Interview 1, teacher A)

Teacher D also showed a misunderstanding about the EALC model. Teacher D's lesson plan included experimental activities that students were asked to connect two resistors in series, measure the voltage and current applied to each resistor, and obtain the value of each resistor. Using experimental results, students were asked to predict the brightness of bulbs when two bulbs were connected in series. Therefore, this process was close to the deductive logical process of predicting other result by applying previous experimental results.

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Using an Inappropriate Inquiry Situation for the EALC Model

The fourth difficulty was about inappropriate use of inquiry situation for the EALC model. As mentioned earlier, to generate hypotheses, a new, curious, and novel phenomenon that cannot be easily explained is appropriate. However, teacher D introduced a situation where students could easily predict or explain based on the law learned previously. Figure 5 is a summary of LP 1 prepared by teacher D.

Figure 5
Outline of Lesson Plan 1 Prepared by Teacher D

Experiment 1: Connection of bulbs in series
(1) The student compares the brightness of a light bulb when one bulb is connected vs. when two bulbs are connected in series. And student observes what happens if one bulb is disconnected when two bulbs are connected in series.
(Student: The brightness of the light bulbs connected in series is getting darker.)*
(Student: If one light bulb is disconnected, the other one goes out).
(2) The student observes the experiment and asks causal questions.
(Student: Why is the light bulb dimmed when two bulbs are connected in series?)
(Student: Why does the rest of the light bulb go out when one bulb is disconnected?)
(3) The students suggest tentative answers to these questions and discuss whether such answers are plausible to explain the observations. … (The rest is omitted.)

* The contents in parentheses indicate students' expected activities in class.

In Figure 5, teacher D intended for students to ask causal questions about their observations at the second step and generate hypotheses as tentative answers to those questions at the third step. This structure was appropriate as a sequence for activities to propose hypotheses. However, in the observational tasks provided at the first step, students are expected to be able to easily predict that the light bulb will get dark when two bulbs are connected in series, and since the actual observation is consistent with their prediction, making it difficult to be a new and novel observation to students. Another situation in which one bulb is disconnected is an easier observation task. Therefore, it was not an appropriate situation for the EALC model.

Missing Scaffolding Strategy to Help Students Think Abductively

As the fifth difficulty, some teachers missed a specific guideline for abductive thinking. When the researcher asked why these teachers did not include step-by-step guides on how to think abductively in their lesson plans, they said:

> "… I don't think I've previously seen some examples of the teacher's activities or specific strategies to help (students) propose hypotheses when I was in college or prepared recruitment examination." (Interview 2, teacher B)

> "… I ask a lot of students 'why', but I don't think I gave them (students) any specific feedback or information about it. I think I just gave students time to think for themselves." (Interview 4, teacher D)

Therefore, this research found that teachers had no experience using these strategies before, which acted as a difficulty in applying the EALC model appropriately.

Lack of Knowledge about Scientific Experiments

The final difficulty was about the lack of knowledge about scientific experiment. When preparing for a science lesson, if teacher does not check actual experimental results in advance, situations in which actual experimental results differ from theoretical predictions often occur during the actual class.

For example, according to teacher C's lesson plan, when two electric bulbs were connected in parallel, the

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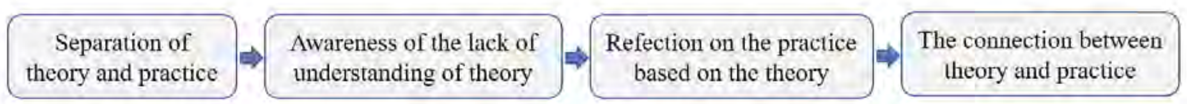
brightness of the bulbs was expected to be the same as when there was only one bulb. This is correct if the voltage at both ends of the battery is constant. However, in an actual situation, the voltage of ordinary battery may drop due to the influence of the internal resistance of the battery when two bulbs are connected in parallel. Therefore, the brightness of the bulb becomes darker in actual situation (Park & Kim, 1998).

However, in the interview, the teacher C said, "I didn't actually conduct experiment when designing an LP 1 and revising it." Therefore, this research found that missing checking factors that might affect the experiment before the actual teaching could cause difficulty in applying the theory into practice in a proper way.

Changes in the Relationship between Theory and Practice

Based on the results of analysis of interviews and lesson plans including revised ones, four stages were identified as the changing process of the relationship between theory and practice through the change of teachers' understanding and the use of the EALC model as shown in Figure 6.

Figure 6
Changing Process of the Relationship between Theory and Practice



Separation of Theory and Practice

In the first stage of Figure 6, as mentioned in the analysis of the difficulties of applying instruction model to actual teaching in schools, some teachers perceived that instruction model was unnecessary. The following is an example:

> "I always had practiced making lesson plan according to the (instruction) model (at the university and when preparing the recruitment examination). Now, in school, I am facing a gap between reality and ideal. I thought it would be convenient and beneficial to just follow the flow (of the textbook) without designing (a lesson plan) using a (instruction) model." (Interview 1, teacher B)

An interesting point was that there were no responses showing that although teachers had tried to use the EALC model in usual teaching situations, they failed due to a lack of understanding of the model, functional difficulties such as how to use it, or other internal and external factors such as teaching environment. Therefore, it is inferred that this negative perception of the instructional model was prejudice or preconception rather than formed by negative experiences. Even teacher C and D, who responded that instruction model was necessary for more effective and systematic teaching, also said that they had no experience to use the instruction model when teaching science at school.

> "I've never designed a lesson plan by applying an instruction model when I teach students at school, even though I have designed it when preparing the second test (of the recruitment examination)." (Interview 1, teacher C)

> "I do not design teaching by considering (an instruction) model. Not once…" (Interview 1, teacher D)

In particular, teacher D expressed the tension when trying to connect the EALC model to practice as follows:

> "The first thing I felt was that I didn't really think about the (EALC) model in school. When I heard the EALC model suddenly (in this research), (I thought) what was that, and it was a feeling of tension. …" (Interview 4, teacher D)

These responses indicated that connecting theory with practice was unfamiliar and unusual to science teachers. As a result, all teachers showed the state of separation between educational theory and practice.

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Awareness of the Lack of Understanding of the EALC Model

In the second stage of Figure 6, science teachers started to recognize their lack of understanding of the EALC model. In this stage, collaborative activities through interview with feedback played an important role and teachers started to rethink about the EALC model itself. For example, for teacher A who confused the abduction with induction, feedback 2 on the meaning and role of abductive thinking was presented with examples. The feedback also explained how the abduction differed from the generalization process by induction or the process of scientific explanation by deduction. Therefore, teacher A said:

> "I certainly thought that I was a little lacking in theoretical foundation. … from the materials (feedback 2) you gave me. … What I felt was that the term 'abduction' is not something that we have used usually, so it (abduction) was confused (to me) a lot with the conclusion through induction." (Interview 3, teacher A)

Teacher D also confused the process of generating hypothesis with the deductive process of prediction. During interviews using feedback, teacher D said that he lacked understanding of the model as follows:

> "As I said before, I thought the answer (hypothesis) should use current, voltage, resistance unconditionally. But I newly know that it is not." (Interview 2, teacher D)

In interviews, some science teachers repeatedly commented on 'creative' or 'diverse' answers (or responses) that students should think for themselves. That is, the teachers thought that any help was unnecessary in the lesson plan to encourage students' own thinking. Of course, it is important for students to search freely and suggest their own ideas. However, with simple instructional sentence alone, such as "Let's think about why", students might have difficulty in generating hypothesis as a tentative answer to the question 'why' because they were unfamiliar with abductive thinking. When the researcher asked teachers why they did not consider a strategy to help students suggest hypotheses more easily, teachers B and D replied that they had not even thought about it.

Therefore, feedback on how to think abductively to generate the hypothesis, which was similar to the guideline described in the research background section, was prepared and presented to these teachers. As a result, they responded that they realized that they did not fully understand the EALC model before.

Reflection on the Practice based on the Theory

In the third stage of Figure 6, teachers reflected on their practices with the lens of theory, recalling their previous teachings in school as well as lesson plans developed in this research. For example, after receiving feedback 2 explaining specific guides for abductive thinking with various examples, teacher C showed the following response:

> "When preparing for teaching before (in school), … I asked the question, "Why does the force act on a conductor when the current flows in a magnetic field?", but the students did not answer at all actually. But when I heard the feedback today, I think that it would have been better if I gave students some hints for the abductive thinking, and if I thought about it more, then I think the student could have answered a little better." (Interview 2 , teacher C)

Regarding this, teacher D also showed a similar response about the reflection on her previous teaching experiences and expressed the necessity of using the model in her teaching as follows:

> "(in the previous teachings) I asked students 'why' a lot, but I did not give them any specific feedbacks or information about it. I just gave them time to think for themselves. … when I saw that students did not give answers, … I did not realize that students did not know how to think abductively. So, I feel I need to think about this a little bit more. I need to think about how I can teach them how to do that (abductive thinking)." (Interview 2, teacher D)

In this third stage, it was worth noting that teachers reflected on their previous teaching experiences in school. This means that their reflections were not limited to a specific lesson plan designed in this research but expanded and generalized to other similar teaching cases of their own.

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The Connection between Theory and Practice

After revisions of LP 1s were completed, teachers were asked to design a different lesson plan (LP 2) with topics that teachers freely chose. Teacher A designed LP 2 with the topic of electric current induced by the moving magnet. Teachers B and D designed LP 2 with the topic of electrostatic induction. Teacher C designed LP 2 with the topic of magnetic field generated by electric current flowing in the coil.

In the final stage of Figure 6, science teachers showed a willingness to connect theory and practice. For example, teacher A, who initially had an inappropriate perception that the instruction model was teacher-centered and too theoretical, changed his initial perception as follows:

> "I think it's quite necessary (to apply a variety of instruction models). Because if I teach without it (instruction model), I will teach with only one frame of mine… or with the most standard (typical or transitional) instruction model that we think of …" (Interview 4, teacher A)

Teacher C also showed a perception related to the need for a connection between theory and practice.

> "In fact, before I met you, I completely forgot about the design of lesson plan and instruction models. After talking to the professor several times, I think there's a difference between teaching by a lesson plan and teaching without it, and also between applying a (instruction) model and not applying it. … I thought it would be more likely for students to learn more if I had … prepared for it (lesson plan using a model)." (Interview 3, teacher C)

Furthermore, teacher A expressed a desire to apply the EALC model to his future classes. That is, he said that he would apply the hypothesis generation process using abduction to the gifted class scheduled for the next day.

> "I will start my gifted class online from tomorrow. I'm also working on what to do with the online class. … I'm going to explain the 'scale' to students tomorrow. (For example) in the case of ants, why can't they grow big? … You just let me know a theory (EALC model) exactly and I will use it tomorrow." (Interview 3, teacher A)

Actually, teacher A applied the EALC model to the gifted class and described his teaching experience in the next interview as follows:

> "… knowing the (EALC) theory, … considering what needs to be incorporated in each phase (of the EALC model), (I can) design a lesson plan and teach a class because I know the points better… I recently did this (application of EALC model) in a gifted class, and I strongly emphasized (the abductive thinking in) the exploration phase." (Interview 4, teacher A)

Teacher B and teacher D also showed a similar response:

> "I think I am going to teach (science class) next year using what I have planned (in this study)." (Interview 4, teacher B)

> "I think it would be good if I use the EALC model for the electricity part in the second grade of lower-secondary school as I designed a lesson plan at this time (in this study)." (Interview 4, teacher D)

In the course of the connection between theory and practice, teacher C hoped to collaborate with professors in other educational situations in the future.

> "It (the use of theory) is still difficult, but I think I've gotten used to it with this opportunity. … (in the past) I felt that reading theory in a book was very different from directly melting (applying) it (theory) in class, … Now, when designing a (other) lesson plan using (different) model, I think it would be good if I can get feedback whether it (application of model) is appropriate or not." (Interview 4, teacher C)

As a result, in the final stage, it was found that all four science teachers designed their lesson plans by applying the EALC model appropriately, along with changes in the perception of the instruction model. Furthermore, there was a willingness to extend the application of the EALC model to other classes. One teacher actually implemented it.

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Discussion

This study is not simply intended to clarify how to effectively use a specific instruction model for teaching practice. Rather, the basic goal of this research is to gain insights and implications for the relationship between educational theory and teaching practice by analyzing specific cases in depth. In other words, this research tried to understand the mechanism and process of linking theory and practice by analyzing the cases in which four teachers utilized the EALC model in their design of teaching lessons.

With this research goal, this research first identified what factors acted as obstacles when science teachers tried to apply a specific instruction model, EALC model. As a result, it was found that inappropriate perceptions of the necessity and role of instruction model hindered the use of this model. That is, teachers misunderstood that instruction model was teacher-centered and that it was not different from their routine teaching ways. They also thought that it was too complicated and abstract. Thus, they had little experience in using specific instruction model in their science class. These negative perceptions on the theory have been reported in many studies as mentioned earlier in the introduction section (e.g., De Corte, 2000; Korthagen & Kessels, 1999; Loughran et al., 2012).

An interesting point was that it could be inferred that these perceptions were not formed through teacher's efforts or experiences of using the instructional model in their everyday teaching in schools, but due to prejudice or preconception. In other words, in the interviews, there were no stories of success or difficulties that teachers experienced in the process of using the model in their school teachings. Even teachers, who had a positive perception of the theory, said that they rarely applied the instruction model in schools.

Although it was not expressed in the interview, it could be expected that there have been several attempts by the teacher for the use of theories. However, it is inferred that such attempts in school were not encouraged in everyday teaching situations and were also not systematic or reflective to develop the use of theory. In this respect, it is necessary to consider a routine system for a close relationship between teachers and teacher educators. For example, AAPT (American Association of Physics Teachers) operates a website that provides experts' recommendations for teachers to solve practical problems, such as "How are research-based assessment instruments developed and validated?" (https://www.physport.org/recommendations/Entry.cfm?ID=124921). Although this is not a real-time and one-on-one system that helps teachers solve their practical problems that arise when applying theories, it is believed that a routine system that can encourage the use of theory and provide professional feedback to teachers who try to apply the theory is one effective way to help them connect theory and practice.

Another interesting finding regarding teachers' perceptions of educational theory was that these perceptions were closely linked to the cognitive aspect, that is, understanding of the instruction model. When teachers were helped to clearly understand the EALC model through a collaborative process with a researcher, their prior perceptions were changed. In fact, many studies have reported a relationship between cognitive and affective aspects in the learning process. For example, recent studies in brain science show that each brain region known to be responsible for affective or cognitive behavior is actually dynamically interconnected (Pessoa, 2008). Therefore, it can be seen that the relationship between the two has a bidirectional character rather than a unidirectional character (Blumenfeld et al., 2006). In other words, learners often engage in cognitive activities with interest and preference, but promoting their understanding through cognitive activities can also strengthen their interest and preference. It can be said that the change of perception in this research corresponds to the latter case.

In the earlier discussion, it was inferred that even if teachers tried to apply the theory in schools, they would not be able to receive professional feedback. Regarding this, this research found that collaboration with experts played an important role in the process of changing the perception of the model by understanding the theoretical model. In this collaboration process, the main focus of the cognitive understanding activities was to understand what inquiry situation was appropriate for the EALC model, how the EALC model differed from other instruction models in terms of inquiry purposes and inquiry skills, and how students should be guided for scientific thinking (i.e., abductive thinking involved in the EALC model). These contents were provided to teachers and could help them overcome difficulties and shortcomings that appeared in teachers' practice.

Teacher education is often conducted as a process of theoretical learning first and then applying it to actual situations. However, problems can be raised with this one-sided approach. For example, Lind (2001) has looked back on his teacher education procedure in university. According to this study, the course usually began in a way that emphasized theory first by reading literature and writing papers. Practical examples of theories were presented at the end part of the course. In this process, students showed positive responses. However, later in the conversation with students, Lind (2001) found that students did not understand what they learned in the course well, although they were the best

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students. Since then, Lind (2001) has completely changed his teaching style by assigning more time to practice at the beginning of the course. In addition, Lind (2001) provided students with the experience of communicating with teachers. As a result, Lind (2001) found that students got more motivated in using theories, enabling them to understand theories deeply. And students' trustworthiness and dependability about theories were increased. Therefore, Lind (2001, p. 2) asserted that "concrete, exemplary problems and task" should be used as "a starting point for teaching abstract theories" in teacher education.

Lind's case implies that theory needs to be introduced to understand the real situation and solve the actual problems. In our research, it was also found that teachers could understand the theory more thoroughly when the theory was introduced to help overcome shortcomings or difficulties found in their practices. Therefore, it is necessary to pay more attention to the approach in which the theory is introduced based on difficulties and needs of teachers in actual situations of teaching.

Among shortcomings in teachers' lesson plans, there was a lack of guidance to help students think abductively. Regarding this guide, it is necessary to refer to the study of Mayer (2004). A constructivist point of view emphasizes that students should be able to construct their own understanding (e.g., Duit & Treagust, 1995). From the perspective of seeing a student as a little scientist (e.g., O'Neill & Polman, 2004), it recommends the process of discovery in which students perform their own inquiry process and discover their own results. However, Mayer (2004) has argued that students who are provided with a guided inquiry, including some hints or feedback on students' inquiry activities, could learn better than a pure discovery method. Although abductive thinking is the key to the EALC model, students are not expected to be familiar with it. Thus, guidance for how to think abductively is essential. That is, when applying the EALC model, science teachers need to have concern about searching and preparing similar situations so that the target phenomenon could be explained through abductive thinking.

A clear understanding of the model not only changed perceptions, but also played a role in leading teachers to reflect their everyday school science teaching as well as lesson plans designed in this research. Looking back on one's own practice with the theory (that is, the EALC model) in mind, lesson plans were modified and gradually developed in a way that the theory was appropriately connected with practice. As many studies have emphasized the importance of reflection in the process of professional development of science teachers (Baird, et al., 1991; Lotter & Miller, 2017; Postholm, 2008), this research also showed that teachers' reflections were included as an important step in the process of moving from a state in which theory was separated from practice to a connected state.

In particular, the reflection in this research was meaningful in that teachers expanded their reflections not only about current lesson plans but also their past everyday practices in schools. Such expansion took place naturally without direct request from the teacher educator. Similarly, in the final stage of connection between theory and practice, one teacher wanted to apply the EALC model not only to a given lesson plan design, but also to other classes in schools. He reported his experience of model application to different topics during teaching. Although this was one instance shown by one teacher, it was a good example of extending the experience of linking theory and practice to other teaching situations.

Conclusions and Implications

Although the information was obtained from small cases where four science teachers applied a specific instruction model to the lesson plan design, meaningful insights about mechanism and process of theory-based teaching could be obtained. In the assumed model of theory-based teaching shown in Figure 1, the main obstacle to the connection between theory and practice was prejudice against theory itself rather than practical difficulties experienced through practice or difficulties caused by an external educational environment. This prejudice could be changed through a deeper and clearer understanding of the theory. By reflecting on teacher's practice based on this clear understanding about the theory, the state of separation between theory and practice could develop into a connected state. In all these processes, collaboration with a teacher educator played an important role. Interestingly, although there was no direct demand or guidance from a teacher educator, one teacher extended the connection between theory and practice to other science classes.

This research revealed what obstacles existed in the state of separation between theory and practice when teachers tried to apply a specific learning model for designing lesson plans, how those obstacles could be resolved, and through what process could lead to a state of connection between theory and practice.

However, since this research included only a single instruction model, EALC model, and a small number of science teachers, there was a fundamental limitation in generalizing research results. In addition, although

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this research was focused on practice of a lesson plan, it had a limitation in that the actual implementation of teaching in the classroom was not analyzed. Therefore, further research is needed to observe more teachers' actual classroom instructions by applying more diverse instruction models.

However, this research was meaningful in that it identified detailed difficulties of teachers in the course of teacher education and revealed the route to professional development of teachers through collaborative efforts to solve them. Not only teachers need to understand students' learning processes for students' learning, but also teacher educators need to understand the process of teachers' learning. Accordingly, further research is needed to clarify the detailed process of teachers' understanding educational theories, solving difficulties in their teaching practices, and developing their expertise.

Declaration of Interest

Authors declare no competing interest.

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