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LEARNING PROGRESSIONS IN LOWER-SECONDARY SCHOOL SCIENCE EDUCATION IN JAPAN

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Abstract. *This research examined whether incorporating learning progress (LPs) in teaching can help Japanese lower-secondary school students systemically understand science concepts. A teaching plan incorporating the learning progressions (LPs) concept was developed. Next, a lesson was conducted for 36 third-year students of a public lower-secondary school in Japan (Hiroshima Prefecture) from the unit of "Ions and Atoms." Then, the portfolios used in the class and the assessment questions after the class were analyzed. The results show that some students understood the concepts systemically at the grade level indicated by the LPs; however, some students did not. The results of this study suggest the following: (1) teachers should examine the appropriate teaching methods in the target unit and incorporate teaching to allow students to engage with what they are learning; (2) students should understand the lower-level concepts related to the target unit based on LPs, and if the level of understanding is insufficient, teachers should incorporate time to review and reconstruct the concepts.*

Keywords: *lower-secondary school science, scientific concepts, learning progressions (LPs), systemic learning*

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Introduction

Since the 1990s, in Europe and the United States, increased research has been conducted on learning progress (LPs) in science education (e.g., Breslyn et al., 2016; Lee et al., 1993; Méheut & Chomat, 1990). Liu and Jackson (2019) analyzed articles on LPs in science education from 2009 to 2018. They noted that research on LPs peaked around 2009, and LPs have come to play an important role in discussions about science education. The United States National Research Council (NRC) defined LPs as "a description of a continuous, more elaborated path of thinking about matters that can be followed by children over a long span of time as something they learn and explore" (NRC, 2007, p. 219). Similarly, Corcoran et al. (2009) defined LPs as "empirically grounded and testable hypotheses about how students' understanding of, and ability to use core scientific concepts, explanations, and related scientific practices grow and become more sophisticated over time." (p. 8) However, it should be noted that creating a systematic learning curriculum is not sufficient to ensure the effectiveness of LPs.

Based on the above, this section presents a review of previous research related to LPs. Smith et al. (2006) developed and proposed LPs for atomic and molecular theories of matter. This is a developmental model of the understanding of eight major concepts (Big Ideas) over a long time—from kindergarten to eighth grade—derived from research on conceptual change by researchers such as Osborne and Cosgrove (1983) in the early days of LP research.

Next, Yao et al. (2017) revised the LPs for energy concepts and tested the validity of LPs with students in grades 8 through 12. The results confirmed the validity of the four conceptual development levels. They also noted that students' progress in understanding energy was nonlinear and complex.

Furthermore, Aufschnaitera and Alonzo (2018) investigated the differences in college students' attitudes toward designing lessons with and without the LPs developed by Alonzo and Steedle (2009). The results showed that the use of LPs led to the consideration of the "building blocks" of students' thought process and enabled teachers to match their teachings to the students' thinking in class.[1)]

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In addition, many other studies have focused on the development of LPs and their evaluation in each domain, such as Fulmer (2015) (force and motion domain), Park et al. (2019) (acid and base domain), Manz (2012) (ecosystem domain), and Plummer and Maynard (2014) (earth and space domain).

In this way, research has developed and continues to develop as LPs are developed for each discipline and then revised, and better ones are proposed. However, although most studies indicate the learning contents to be taught in each grade, they do not clearly indicate the specific teaching. This means that "appropriate teaching," which is important for the effective functioning of LPs, is not clearly indicated. This is supported by Liu and Jackson's study (2019) who pointed that, while many researchers have developed LPs in science, there is still a dearth of research focused on actual teaching in the classroom. On the other hand, although not a study of LPs, Taber (1994, 1997) conducted a series of investigations with key stage 4 students and proposed an alternative "molecular framework" for understanding ionic bonding. This consisted of (1) the valency conjecture, (2) the history conjecture, and (3) the just forces conjecture. They found that some students retained more than one framework. To enhance students' conceptual understanding, it would be effective for teachers to understand the framework that students have and teach in reference to those frameworks.

Regarding research on LPs in Japan, Yamaguchi and Deguchi (2011) considered how research on LPs could contribute to conceptual change research. They stated that the current science curriculum in Japan has an affinity with LP research because the course of study for science has been revised to emphasize systemically the learning content across primary, lower-secondary, and upper -secondary schools. Furthermore, Suzuki et al. (2015) used LPs to clarify the relationship between developing conceptual understanding of ecosystems and developmental stage (grade) in Japanese primary schools. The results showed a significant relationship between developing a conceptual understanding of ecosystems and the developmental stage (grade). However, research on LPs in Japan is limited and not very advanced. There has been no practical research on "appropriate teaching." In addition, "lesson study" has been actively conducted in Japanese schools and was widely researched by Lewis (1995). Based on their own experiences working in Japanese schools, Ermeling and Ermeling (2014) stated that Japanese teachers meticulously plan their teaching through "lesson study"; however, this is not based on LPs.

Based on the above background, this study focuses on science teaching in Japanese classrooms, and provides a detailed analysis of teaching from the perspective of LPs. To this end, the following research questions were formulated:

1) If teachers adopt the LPs approach, will students be able to systemically understand science concepts?
2) If so, what kind of teaching is effective?
3) If not, how should teachers teach them?

Systemic Conceptual Understanding

This study focused on the ideas of the Inquiring Project—a research group that conducted early research on LPs (e.g., Wiser et al., 2009). The Inquire Project lists four theoretical components to be considered when developing a curriculum, among which we focused on the components of stepping stones, which are used in the context of connecting with other concepts. We believed that having students form this stepping stone at the target grade level would lead to a better understanding of the concept.

Based on the above and focusing on future conceptual understanding, in this study, "systemic conceptual understanding" is viewed as an addition to conceptual understanding at the target grade level, forming a foothold that is considered necessary with an eye to the next grade level.

Research Methodology

First, in this study, a teaching plan incorporating the concept of LPs was developed. Next, an evaluation questionnaire to assess the students' conceptual understanding after the implementation of the LPs (e.g., NRC, 2007), a portfolio to see the descriptions in the learning process, and an open-ended questionnaire to examine the relationship between the learning content of this study and the concepts in upper-secondary school chemistry presented in the LPs were developed. Further, a portfolio was created with the descriptions of the learning process and an open-ended questionnaire to examine the relationship between the content of this study and the concepts in upper-secondary school chemistry presented in the LPs. Then, the students'

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systemic understanding of the concepts was clarified by conducting a class practice in the unit, "How Ions and Atoms Form," and analyzing the assessment questions and portfolio entries after the practice. In addition, the relationship between the contents of this study and the concepts in upper-secondary school chemistry as presented in the LPs was examined by analyzing the descriptions in the open-ended questionnaire that was administered after the practice. Through the above procedures, suggestions for creating a systematic teaching plan for conceptual understanding were derived. The three elements of LPs are shown in Figure 1. In addition, since this study is validated through a qualitative analysis of science lessons, no pre-test was given. In other words, the study has been designed on the assumption that if students could understand science concepts systemically, the results would appear on worksheets and post-tests in class.

Figure 1
Elements of LPs

(1) Concepts and thoughts that the student has acquired at the beginning of learning
(2) Concepts and thoughts that you want the student to have acquired at the end of the study
(3) Concepts and thoughts in between (1) and (2)

Creating a Teaching Plan

To create a teaching plan that is four hours long and that incorporates the concept of LPs in the unit "The Origin of Ions and Atoms," which is the subject of the practice, we first extracted issues from the conventional teaching plan. Table 1 shows the traditional teaching plan developed with reference to the teaching plans covered in Japanese textbooks published in 2016 (five publishers).

Table 1
Conventional teaching plan

Session (50 min)	Study Contents
1	Atomic Formation Understand that an atom is made up of a nucleus and electrons. Students will also understand that atoms have + electrified protons and - electrified electrons, and that since the number of protons and electrons is equal, the atom is not electrified.
2	Ion Understand that atoms are electrically charged and are called ions. Understand how ions of sodium, magnesium, and chlorine atoms are formed.
3	How Ions Are Formed Understand the ionic equation. Understand the typical ions.
4	Ionization Understand the ionization of sodium chloride and hydrogen chloride and represent it using ionic equations. Think of a reason why current does not flow in a non-electrolyte and present it.

The LPs used as references are listed in Table 2. In this study, the LPs described in the New Science Education Framework A Framework for K-12 Science Education (NRC, 2012), were referred to. They are also often cited in LP studies. The LPs in this document describe the development of conceptual understanding in each grade band. Further, since the third grade of lower-secondary school was the target grade in this study, the LPs from the third grade of lower-secondary school to the third grade of upper-secondary school were used as a reference.

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Table 2
LPs[2)] in "Structure and Properties of Matter"

Grade in School	Development of Understanding of Concepts and Thoughts
Lower-secondary school: 3rd grade- Upper-secondary school: 3rd grade	Concepts about the structure of atoms Concepts related to the order and arrangement of atoms in the periodic table Concepts related to the periodic table and the number of outermost electrons
Primary school: 6th grade- Lower-secondary school: 2nd grade	Concepts related to the components of matter The concept of the difference in thermal motion of atoms and molecules in the three states of matter The idea that state changes can be explained and qualitatively predicted by using models
Primary school: 3rd grade- Primary school: 5th grade	The concept of the existence of matter Concept of state change (gas) The concept of conservation of materials
Kindergarten- Primary School: 2nd grade	Concept of the diversity of material types Concepts of state change due to temperature change (solid and liquid only) The idea that matter can be observed and measured

In the aforementioned table, the conventional teaching plan, and the LPs corresponding to the target unit and extracted the issues were compared. From the viewpoint of systemic conceptual understanding, it was considered that the students could not understand the essence of the differences in valence and the ease of forming ions for each atom and that the ionic formula was treated as a mere acquisition of knowledge. Therefore, in addition to the conceptual understanding of the target unit, this study thought that the systemic conceptual understanding specified earlier could be achieved by having the students establish a foothold through "judging the valence of the ionic formula from the arrangement of atoms in the periodic table," and decided to create a teaching plan.

Based on the above, a specific teaching plan was developed based on the research of Kikuchi et al. (2010), who stated that ions are a form of basic particles that make up matter and that they are a fundamental concept for learning about matter. They conducted a class on the structure of atoms and ions for first graders in lower-secondary school. They reported that students did not find ions so difficult and showed a high level of understanding. In this study, the LPs from the third grade of lower-secondary school to the third grade of upper-secondary school were incorporated so that students could fully understand the contents that are treated as developmental in the textbook, such as electron configuration. In addition, for (1) shown in Figure 1, a review of atoms and molecules learned in the second grade of lower-secondary school was included in the first class. Table 3 shows the teaching plans that this study prepared.

Table 3
Teaching Plan Used in this Study

Session (50 min)	Study Contents
	Atomic Formation
1	Learn about the properties of atoms. Understand that an atom is made up of a nucleus (consisting of protons and neutrons) and electrons. Know that the number of protons in an atom determines the type and atomic number of that atom.
	Ion
2	Understand ions and the periodic table. Determine the excess or deficiency of electrons in each family based on the periodic table and the electron configuration of each atom (groups 3-12 will not be discussed).
	How Ions Are Formed
3	Identify the positions of metal and non-metal atoms in the periodic table. Guess whether they are more likely to be a cation or an anion depending on their family. Listen to an explanation of how sodium and chlorine atoms form ions and their ionic formulas. Deepen the understanding of how ions are formed by watching an animation showing the transfer of electrons.

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Session (50 min)	Study Contents
	Ionization
4	Students listen to an explanation of ionization and use model diagrams and ion equations to describe the ionization process. In this way, they deepen their thinking while watching an animation showing the ionization process. Also, think about why current does not flow in non-electrolytes.

Note: Underlined parts indicate areas where the LPs approach was adopted.

Creating Assessment Questions

To grasp the status of the students' understanding of the concept (2) shown in Figure 1, we created an evaluation question. Specifically, students were asked to explain the dissolution of magnesium chloride in water through: (1) a model diagram and an ionization equation, and (2) a written explanation. In (1), students were asked to understand the concepts related to the structure of atoms and to draw appropriate model diagrams; in (2), students were asked to understand the relationship between the structure of atoms and the periodic table and to guess the valence of ionic formulas. Appendix 1 presents the evaluation questions. In addition, the evaluation criteria for the assessment questions were developed based on the conceptual development level indicated by Handenfeldt et al. (2013). The evaluation criteria are presented in Table 4. In this study, based on the teaching plan shown in Table 3, an S evaluation was set as the achievement goal to provide teachings related to the periodic table and electron configuration.

Table 4
Evaluation Criteria for Evaluation Questions

Evaluation	Appraisal Standard
S Objectives	The student can guess the ionic equation in relation to the periodic table, write the model diagram and ionization equation, and explain ionization
A	The student can write the ionic equation, model diagram, and ionization equation and explain ionization, although they cannot relate it to the periodic table
B	The ion formula is incorrect, but the student can distinguish between atoms and ions in the model diagram and explain ionization
C	Incorrect explanation of ionic equations, model diagrams, and ionization (atoms and ions are not distinguished)
D	Incorrect explanation of the ionic equation, model diagram, or ionization (does not understand that particles break apart, or no response)

Portfolio Preparation

Regarding (3) shown in Figure 1, a portfolio (hereafter referred to as "PF") was created to observe the students' descriptions of the learning process. Specifically, the students were given the task of explaining the dissolution of NaCl in water through: (1) model diagrams, (2) ionization equations, and (3) written explanations. In this lesson, students were expected to relate the periodic table to the electron configuration, relate the electron configuration to the valence of ions, and appropriately describe what a substance looks like when dissolved in water. The prepared PF is shown in Appendix 2.

Questionnaire Preparation

Smith et al. (2006) stated that questioning is an important factor in the reconstruction of concepts. Therefore, a free-response questionnaire was developed and the questions that arose among the students through this study were analyzed to examine the relationship between this study's content and the concepts in upper-secondary school chemistry as presented in the LPs. First, the content of each class was presented, and the students were asked

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to answer on a four-point Likert scale whether they found it easy to understand. Next, based on their responses to the Likert scale, the students were asked to write freely about what they found easy to understand, what they found difficult to understand, and what they wondered or wondered about throughout the four hours of class. This study decided to analyze the free-text portion of the questionnaire. The questions to be addressed in this questionnaire are related to the contents of the four-hour class, this study was developed without using existing ones. The questionnaire is presented in Appendix 3.

Classroom Practice

The practice was conducted in June 2018 for 36 third grade students of a public lower-secondary school in Japan (Hiroshima Prefecture) for the unit "How Ions and Atoms Form." The teaching process is shown in Table 5. One class (50 minutes) was held per week, and four classes were held for one month. The content and methods of the study were explained to the lower-secondary school students and their teachers, and their understanding was obtained. In addition, written consent was obtained from the students and their parents/guardians.

Table 5
Teaching Process

Class	Study Contents
1	Atomic Formation
2	Ion
3	How Ions Are Formed
4	Ionization
	Implementation of Assessment Questions and Questionnaires

Class 1

The aim of the first lesson was to remind the students about the properties of atoms and help them understand that the number of protons in an atom determines the type of atom and its atomic number. When explaining atoms, students were asked to think about whether protons or electrons move more easily in the structure of an atom. The students were also told that the number of protons in an atom determines the type of atom and its atomic number. Additionally, the students were told that an atom is made up of a nucleus with electrons orbiting around it.

Class 2

The aim of the second lesson was to help the students understand the properties of the periodic table from the electron configuration. First, the students reviewed the periodic table and wrote the names of the atoms up to atomic number 20 on the worksheet. After reviewing the previous lesson, they confirmed that the number of protons determines the type of atom and the atomic number and were asked to estimate the number of protons and electrons in each atom. The students were then asked to estimate the number of protons and electrons in each atom. After explaining the electron configuration, the students were asked to deduce the properties of the periodic table from the figures and tables in the worksheet. The worksheet is provided in Appendix 4.

Class 3

The aim of the third lesson was twofold: first, to help the students understand that metal atoms tend to be cations and non-metal atoms tend to be anions from the periodic table; second, to help the students determine the valence of the ionic formula when ions are formed from the periodic table. First, the students were asked to identify the positions of the metal and non-metal atoms, in the periodic table. Then, the students were asked to guess whether they were more likely to be cations or anions depending on their families and to notice that metal atoms are more likely to be cations and non-metal atoms are more likely to be anions. Based on the learning in the second period and the previous content of this period, the students explained how sodium and chlorine atoms form ions and their ionic formulas. The students were shown an animation of the transfer of electrons, to deepen their understanding of how ions are formed.

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Class 4

The aim of the fourth lesson was to enable students to express the ionization process appropriately using model diagrams and ionic equations based on what they had learned thus far. In this lesson, students were shown an animation of ionization to deepen their understanding. In addition, the students were asked to think about why current does not flow through non-electrolytes compared to electrolytes.

Research Results

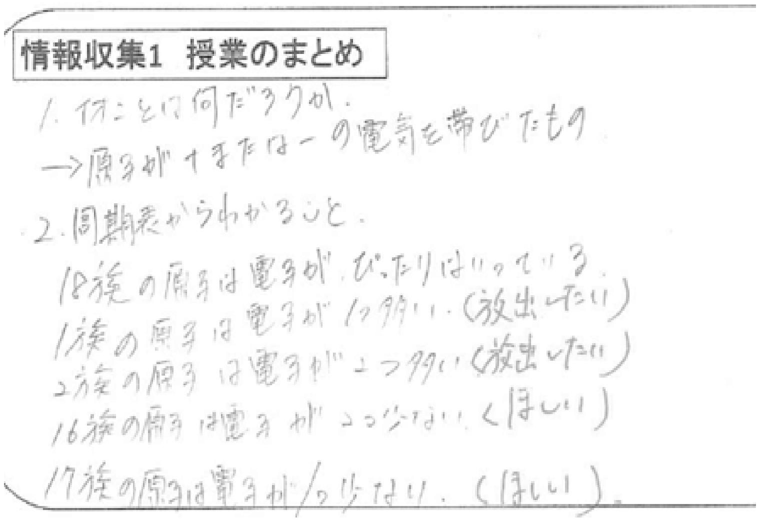
Results of Assessment Questions

First, to clarify the students' systemic conceptual understanding, the assessment questions and descriptions in the PFs were analyzed. According to Watanabe and Matsuo (2018), element (3) of the LPs shown in Figure 1 is a stepping stone to reach element (2). Furthermore, the relationship between the results of the assessment questions and the PF descriptions was considered. Additionally, the results of the evaluation questions and descriptions in the PF were discussed. By analyzing the descriptions in the questionnaires, the relevance of the study's contents and the concepts in upper-secondary school chemistry presented in the LPs were examined, and suggestions for teaching planning were derived. The details of this are described below.

Table 6
Tabulation Results of Evaluation Questions

Evaluation	Number of Students
S	12
A	11
B	9
C	4
D	0

Figure 2
Example of a Student's (S-rated) Description in PF


情報収集1　授業のまとめ
1. イオンとは何だろうか.
→原子が＋または－の電気を帯びたもの
2. 周期表からわかること.
18族の原子は電子がぴったりはいっている
1族の原子は電子が1つ多い.（放出したい）
2族の原子は電子が2つ多い（放出したい）
16族の原子は電子が2つ少ない（ほしい）
17族の原子は電子が1つ少ない.（ほしい）.

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Class discussion
1. What is an ion?
→Atoms are charged with + or - electricity.
2. What can we learn from the periodic table?
→Group 18 atoms are filled with electrons.
→Group 1 atoms have one more electron. (Wants to release it)
→Group 2 have two more electrons. (Wants to release them)
→Group 16 have two fewer electrons. (Wants to gain them)
→Group 17 have one more electron. (Wants to gain it)

Results of the Evaluation Questions

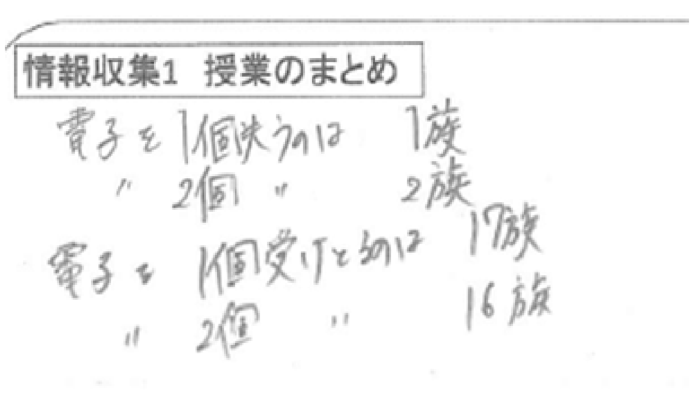
First, the assessment questions for all the target students were analyzed, and the number of students for each criterion was tabulated by four graduate students specializing in science education based on the assessment criteria created. Table 6 presents the results of the tabulation. Although more than 60% of the students scored A or higher, which is considered the achievement target in regular classes, only 30% of the students understood the concepts systemically (S rating) at the third-grade level, which is the standard in LPs.

Examination of PF by Descriptive Analysis

From the analysis of the evaluation questions, it was expected that students with an S rating have to understand the concepts systemically at the upper-secondary school level if appropriate teaching based on the LPs is given in the future. However, some students (grades A, B, and C) did not systemically understand the concepts. To understand the reasons for this, we analyzed the students' understanding of each class content based on the descriptions in the PF.

In the description of the S-rated students shown in Figure 2, the formation of the foothold set up, which focused on the excess or deficiency of electrons in each family, was observed. Atoms were used as the subject and the electron configuration of noble gases as the object of comparison; for example, "Atoms in group 1 have one more electron (to be released)." This could be because, during the first lesson on learning about the formation of atoms, the students understood that electrons on the outside of atoms are exchanged; during the second and subsequent lessons, they were able to utilize the content of the first lesson on learning to recognize the regularity of the periodic table and relate the exchange of electrons to the periodic table. Alternatively, in the PFs of the students with grades below A shown in Figure 3, there were almost no descriptions of atoms and electron configurations. There are two possible reasons for this: first, the students did not fully understand the nature of atoms in the first lesson and the content of the second lesson on electron configuration. Second, the students did not fully understand what they learned about the electron configuration in the second lesson.

Figure 3
Example of a Student's (score A or lower) Description in the PF



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Class discussion
Losing one electron is in group 1.
Losing two electrons is in group 2.
Gaining one electron is in group 17.
Gaining two electrons is in group 16.

Examination of Evaluation Questions through Descriptive Analysis

In this study, the reviewed items were limited to the review of atoms and molecules. We proceeded on the assumption that the students understood the content up to the second grade of lower-secondary school. However, students who received a grade of B or lower, especially in the evaluation criteria shown in Table 5, were considered to have problems with systemic conceptual understanding.

Therefore, to derive suggestions for preparing teaching plans for systemic conceptual understanding, we analyzed the descriptions in the evaluation questions of the students who received a grade of B or lower. As a result, two main errors were found: first, in the model diagram shown in Figure 4, there was an error in the number of particles before and after the dissolution of the substance; second, in the ionization equation shown in Figure 5, there was an error in the number of atoms before and after the reaction. Second, the number of atoms before and after the reaction in the ionization equation shown in Figure 5 was incorrect. These results suggest that the students who received grades of B or C confused the valence of ions with the number of particles, or the concept of particle conservation was not sufficiently understood in class.

Figure 4
Students' (score B-rated) Descriptions of the Assessment Questions
(Errors found in the model diagram)

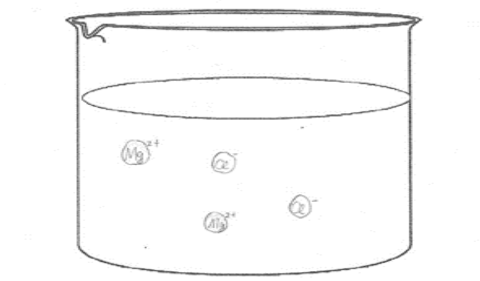
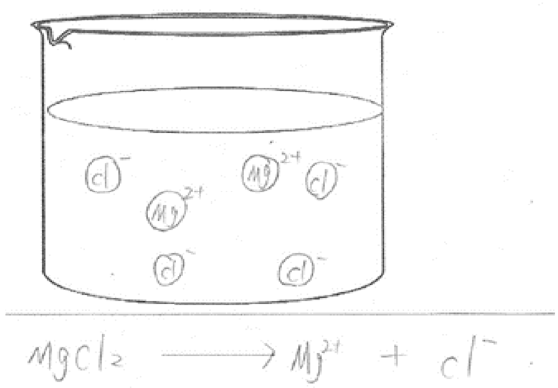


Figure 5
Students' (score B-rated) Descriptions of the Assessment Questions
(An error was found in the ionization formula)



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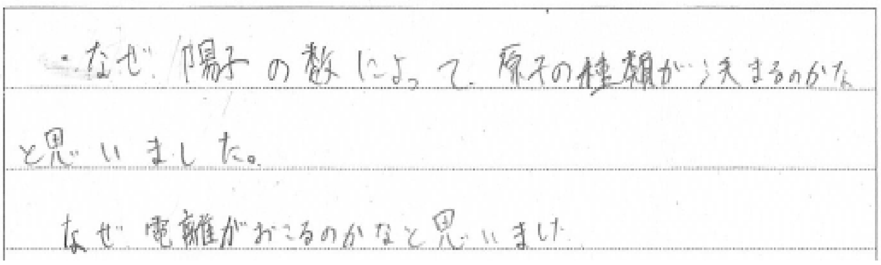
Examination of the Open-ended Questionnaire by Descriptive Analysis

The unit in this study connected the concepts of atoms and molecules learned in the second grade of lower-secondary school with the concepts of structure and change of matter learned in upper-secondary school chemistry. By analyzing the descriptions in the open-ended questionnaire, the relationship between the contents of this study and the concepts in upper-secondary school chemistry presented in the LPs were examined.

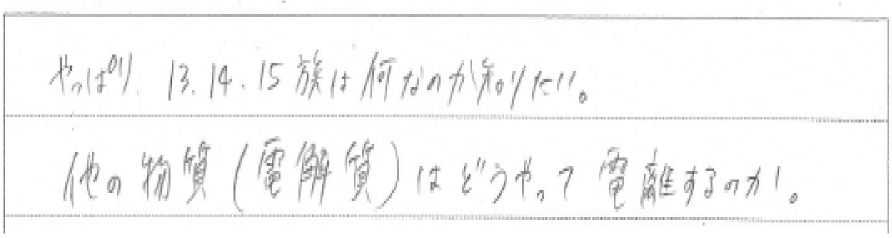
For example, the responses of students A and B in their questionnaires are shown in Figures 6 and 7. Student A's question, "Why does the number of protons determine the number of atoms?" and Student B's question, "What are groups 13, 14, and 15?" Most interactions are determined by electrical forces within or between atoms. This may be important in understanding that "a stable form of matter is one in which electrical and magnetic energies are minimized." While these questions were asked to help students understand the concept systemically, not all students asked these questions. This may be because there were no learning activities to apply the understood concepts, and so it was unclear at what level the students understood the concepts. Therefore, to promote systemic conceptual understanding, it is necessary to improve the teaching plan so that students can understand the concepts at each grade level and have questions that will lead from one level of learning to the next.

Figure 6
Student A's Responses on the Questionnaire


・なぜ、陽子の数によって、原子の種類が決まるのかな
と思いました。
なぜ、電離がおこるのかなと思いました

I wondered why the number of protons determined the type of atom.
I wondered why ionization occurs.

Figure 7
Student B's Responses on the Questionnaire


やっぱり、13.14.15族は何なのか知りたい。
他の物質（電解質）はどうやって電離するのか！。

I want to know how the 13, 14, and 15 groups work.
I wonder how other substances (electrolytes) are ionized.

Discussion

Based on the results obtained, this study will examine whether the students were able to understand the concepts in a systemic way when the teacher incorporated LPs into the instructional planning and appropriate teaching.

According to the results of the assessment questions shown in Table 6, more than 60% of the students

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achieved the achievement target (A rating or higher) in the third grade students of lower-secondary school. Of these, about 30% of the students reached the achievement target (S rating) that we aimed for by introducing the LPs. In this study, the reason for this significant result was that the teacher added the LPs to the conventional teaching plan in Japan, prepared the teaching plan, and taught the students appropriately. In other words, it was effective to give the students the periodic table and let them understand the valence of ionic formulas in this research, although it is common not to deal with electron configurations in the third grade students of lower-secondary school in Japan. For the students, the periodic table became a stepping stone and supported their thinking when they considered the transfer of electrons. This is in line with the results of a study conducted by Aufschnaitera & Alonzo (2018) on university students, and this study confirmed the effectiveness of the foothold even when the target group was lower-secondary school students. Furthermore, the PFs of the students who reached the S level shown in Figure 2 showed the systematic understanding of concepts that this study expected, and it is expected that their thinking methods will be further refined in the future growth process.

Another possible explanation for the significant effect of this study on students' systemic conceptual understanding is lesson study in Japan. Lesson study is a traditional training method used in many schools in Japan and has a history of over 100 years. Lewis (1995), Ermeling & Ermeling (2014) acknowledge that lesson study is an effective tool in improving teachers' teaching skills. Although the lower-secondary school, to which the teachers participating in this study belong, conducts lesson studies, they do not focus on LPs. Therefore, it is unlikely that the lesson study directly influenced the teachers' teaching. However, the teachers themselves may not have been aware of it, but they may have unconsciously developed their teaching skills through the lesson study, and it cannot be said that this is unrelated to the results of this study.

However, the PFs of the A-rated students and below shown in Figure 3 contained almost no descriptions of electron transfer or electron configuration. In addition, the PFs of the B-rated students shown in Figures 4 and 5 did not understand the concept of conservation of mass and contained errors in the ionization equation. Furthermore, in Table 6, the students whose results of the evaluation questions were below the B rating accounted for about 40% of the total. This study deduces that the reason for this result may be that the students did not fully understand what they were learning because there was much lecturing by the teacher and little discussion among the students. It is important to include not only the teacher's lecture but also the students' discussion activities so that the students can organize and expand their ideas (Forawi, 2016). It is also important to stop thinking that students are learning in a uniform way as intended by the teacher if they follow the instructional plan developed by incorporating the LPs perspective. Corcoran et al. (2009) argue that most LPs are designed with the assumption that students' thinking proceeds in a linear fashion, but in reality, students' thinking follows a non-linear path. Corcoran et al. (2009) pointed out that most LPs are designed assuming a linear progression of students' thinking, but in reality, students' thinking may follow a non-linear path. In addition, Castro-Faix et al. (2021) found that many students were able to understand concepts systematically with the prepared LPs, but some were not, and stated that the LPs need to be improved to match students' thinking. Ermeling & Ermeling (2014) stated that it is important for teachers to monitor students' progress in class and support their learning by patrolling between desks. These are in line with the ideas mentioned above. In addition, before starting to teach a unit, it is good to include an activity to review the teaching plan with colleagues and revise it if necessary. This is an activity to improve the validity of the instructional plan that has been created. In addition, it is recommended to include activities that allow students to have a clear goal of their conceptual understanding and to constantly monitor their own learning status. This is an activity to strengthen students' metacognitive abilities so that they can learn autonomously. By doing so, it is hoped that even students with A-rated students will become more aware of their past learning and future learning, rather than merely acquiring knowledge and understanding concepts. This is in line with Lytle et al. (2019) who suggested that students' learning levels and progress need to be monitored and the appropriate adjustments should be made during lessons. Manz (2012) also stated that "there is much work yet to be done in understanding the complexities of this perspective on the development of content knowledge and determining how best to support teachers in orchestrating it" (p. 1102).

On the other hand, Figure 6 and 7, in which the students described their questions and wonderings during the learning process, contain information that will lead to learning in upper-secondary school. Therefore, the findings of this study should contribute to future research on LPs.

By the way, this research has some limitations. First of all, the sample size of this study was small, and

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the number of students was 36. In addition, the number of classes conducted was four. Second, this study focused on qualitative analysis and did not conduct pre-testing of students' conceptual understanding. In the next phase of the research, pre-testing should be conducted, and statistical methods should be used to further analyze the results. Finally, teachers and students need to be interviewed to gather data on topics that cannot be explored in writing.

Conclusions and Implications

In science education, research on LPs has been actively conducted for about 30 years, and although many studies have proposed learning contents to be taught in each grade, they have not clearly indicated specifically what kind of teaching is beneficial. This is an issue for LPs research. Therefore, this study was conducted to clarify whether or not students can systemically understand science concepts in Japanese lower-secondary school when teachers incorporate the LPs concept into their teaching.

The analysis of the present study confirmed that a certain number of students can systemically understand concepts if the instructional plan is prepared by incorporating the LPs and the teacher provides appropriate teaching. In other words, the results confirmed what has been discussed for many years in previous studies, that students do not always understand concepts systemically simply by adopting the LPs and organizing the contents to be learned in each grade. Therefore, while it is important to develop and validate instructional plans based on the LPs, it is not enough to ensure students' systemic understanding of concepts. For students, learning about electron configurations through the periodic table, rather than systemically memorizing ionic equations, is a stepping stone to deeper thinking. Therefore, the teacher must prepare some kind of stepping stone for the students. Furthermore, since students' thinking is not necessarily linear, but may follow a non-linear path, it is necessary to keep track of the state of students' thinking and provide guidance accordingly.

Based on the above, this study makes three suggestions. Under the assumption that a validated instructional plan for LPs has been prepared, teachers should examine what are the useful stepping stones for students to think and prepare appropriate stepping stones. Teachers should also develop tools to monitor students' thinking in class so that they can provide optimal instruction to each student independently. Finally, teachers should be provided with practical support for using the developed LPs so that they can use them effectively.

Notes

1. The documents obtained and surveyed were the Journal of Educational Psychology, Journal of Science Education, Journal of Science Education (Bulletin), Journal of the Japanese Association for Subject Education, Journal of the Japanese Society for Educational Technology, *Chemical Education*, *Journal of Research in Science Teaching, Science & Education, Science Education, Studies in Science Education, and International Journal of Science Education* from 1995 to 2021. In addition, the following journals have been published: *Science & Education*, *Science Education, Studies in Science Education, and International Journal of Science Education.*
2. The LPs shown in Table 2 were compiled by the author based on the descriptions in A Framework for K-12 Science Education (NRC, 2012).

Declaration of Interest

Authors declare no competing interest.

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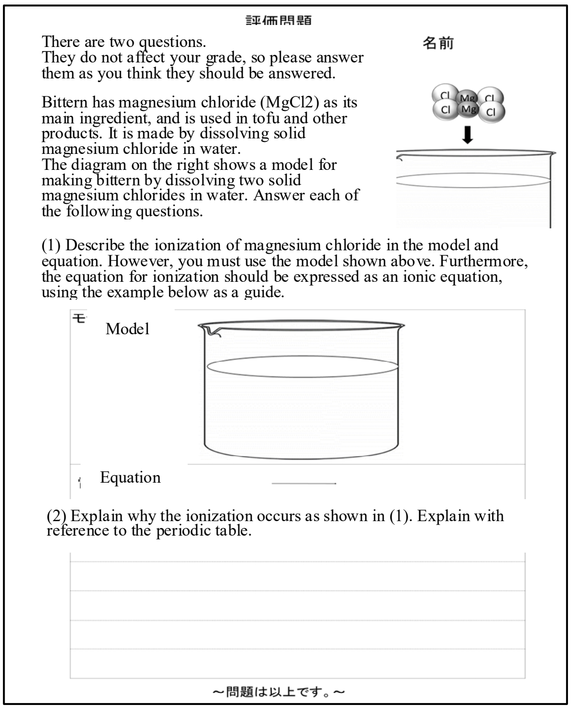
Appendix

(Appendix 1) Assessment Test


評価問題

There are two questions.
They do not affect your grade, so please answer them as you think they should be answered.

名前

Bittern has magnesium chloride (MgCl2) as its main ingredient, and is used in tofu and other products. It is made by dissolving solid magnesium chloride in water.
The diagram on the right shows a model for making bittern by dissolving two solid magnesium chlorides in water. Answer each of the following questions.

(1) Describe the ionization of magnesium chloride in the model and equation. However, you must use the model shown above. Furthermore, the equation for ionization should be expressed as an ionic equation, using the example below as a guide.

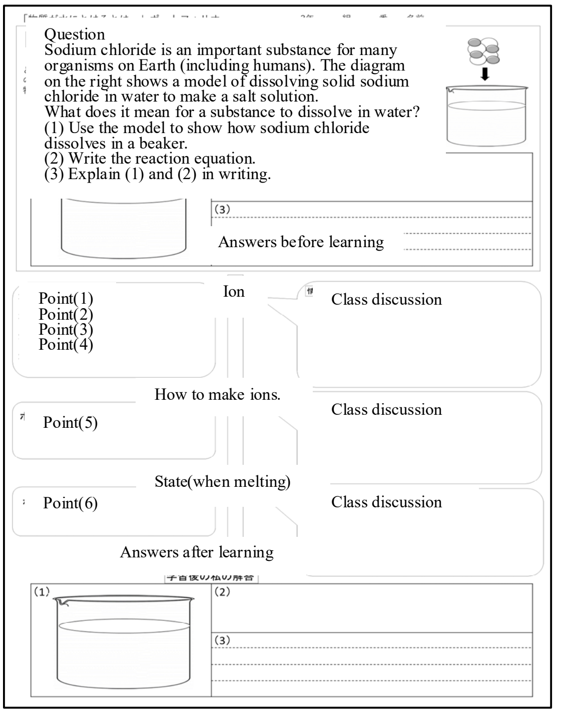
Model

Equation

(2) Explain why the ionization occurs as shown in (1). Explain with reference to the periodic table.

～問題は以上です。～

(Appendix 2) Portfolio


Question
Sodium chloride is an important substance for many organisms on Earth (including humans). The diagram on the right shows a model of dissolving solid sodium chloride in water to make a salt solution.
What does it mean for a substance to dissolve in water?
(1) Use the model to show how sodium chloride dissolves in a beaker.
(2) Write the reaction equation.
(3) Explain (1) and (2) in writing.

(3)
Answers before learning

Point(1)
Point(2)
Point(3)
Point(4)

Ion

Class discussion

How to make ions.

Point(5)

Class discussion

State(when melting)

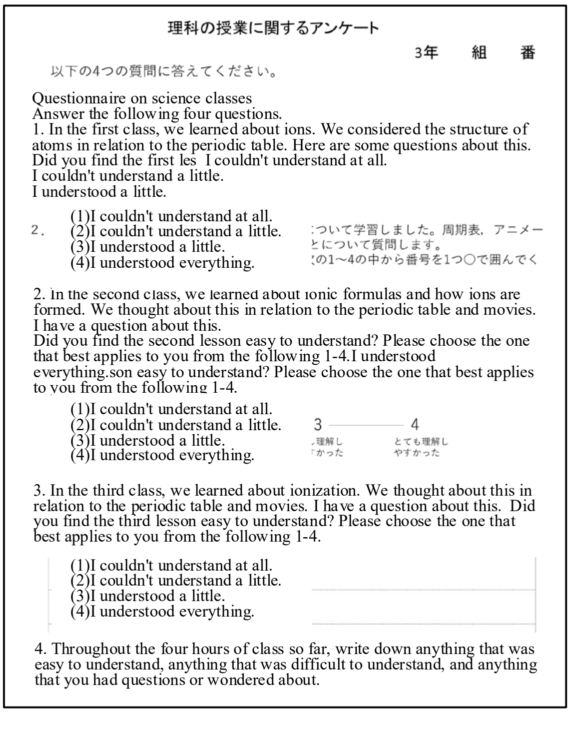
Point(6)

Class discussion

Answers after learning

(1) (2)
(3)

(Appendix 3) Questionnaire


理科の授業に関するアンケート

3年　組　番

以下の4つの質問に答えてください。

Questionnaire on science classes
Answer the following four questions.
1. In the first class, we learned about ions. We considered the structure of atoms in relation to the periodic table. Here are some questions about this.
Did you find the first les I couldn't understand at all.
I couldn't understand a little.
I understood a little.

(1)I couldn't understand at all.
(2)I couldn't understand a little.
(3)I understood a little.
(4)I understood everything.

2. In the second class, we learned about ionic formulas and how ions are formed. We thought about this in relation to the periodic table and movies.
I have a question about this.
Did you find the second lesson easy to understand? Please choose the one that best applies to you from the following 1-4.I understood everything.son easy to understand? Please choose the one that best applies to you from the following 1-4.

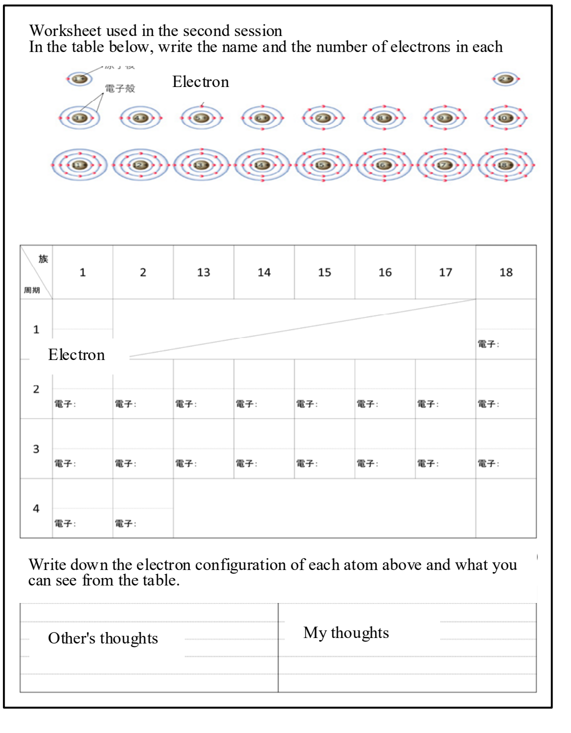
(1)I couldn't understand at all.
(2)I couldn't understand a little.
(3)I understood a little.
(4)I understood everything.

3. In the third class, we learned about ionization. We thought about this in relation to the periodic table and movies. I have a question about this. Did you find the third lesson easy to understand? Please choose the one that best applies to you from the following 1-4.

(1)I couldn't understand at all.
(2)I couldn't understand a little.
(3)I understood a little.
(4)I understood everything.

4. Throughout the four hours of class so far, write down anything that was easy to understand, anything that was difficult to understand, and anything that you had questions or wondered about.

(Appendix 4) Worksheet Used in the Second Session


Worksheet used in the second session
In the table below, write the name and the number of electrons in each

Electron

族 / 周期	1	2	13	14	15	16	17	18
1	Electron							電子:
2	電子:	電子:	電子:	電子:	電子:	電子:	電子:	電子:
3	電子:	電子:	電子:	電子:	電子:	電子:	電子:	電子:
4	電子:	電子:						

Write down the electron configuration of each atom above and what you can see from the table.

Other's thoughts	My thoughts

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