Middle School Students' Knowledge State Analysis about Light

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Abstract: In this study, 15 evaluation questions about light were developed and presented to 30 middle school students, and then the theory of knowledge space was used to analyze the status of the middle school students' knowledge about light. Not only was the state of the students' knowledge about light intended to be measured by schematizing the knowledge hierarchy obtained; the data obtained were also intended to be used as basic materials to improve the teaching methods used. To achieve the purpose of this study, the evaluation results, the individual knowledge state, and the hierarchy of questions were analyzed. As a result, different knowledge structures were found in the individuals and groups, and it was determined that individuals and groups should be diagnosed differently. In addition, the implication that there is a connection between each question and the individual knowledge state was drawn.

Key words: Knowledge space, knowledge state, hierarchy, evaluation

Ⅰ. Introduction

Many researchers have pointed out that students do not have a full and accurate understanding of the concept of light (Buty & Mortimer, 2008; Galili & Hazan, 2000; Glodberg & McDermott, 1986; Guesne, 1985; Stead & Osborn, 1980; Wyrembeck & Elmer, 2006). Many studies have thus been carried out to address this problem (Kwon *et al.*, 2006; Oh & Kim, 2002; Lee *et al.*, 2004; Buty & Mortimer, 2008; Wyrembeck & Elmer, 2006). While it is true that many students do not have a systematic understanding of the concept of light and have difficulty learning it, it is likewise true that many teachers also do not have a systematic understanding of the concept, thus having difficulty teaching it to their students and not being able to give their students systematic feedback regarding the degree to which they learned the concept (Paik & Jung, 2009; Lee *et al.*, 2004; Jung & Kim, 2005; Akerson & Morrison, 2006). Wenglinsky (2000) suggested that teachers have a great effect on students' academic achievement, but students solve problems and try to understand the structure of a problem by applying what they already know. Sometimes, they acquire new knowledge with creative ideas (Anderson, 1995). According to Durva (1985), human intellectual development has a sequence of systematization of cognitive functions. The low-level functions during learning are based on the high-level ones, and a hierarchy exists when functions related to a specific knowledge system are acquired. Consequently, the hierarchy of concepts can be regarded as an essential requirement for carrying out high-level functions in learning (Jung *et al.*, 1996; Bergan, 1980). The elements and functions that students should study to attain the final purpose of learning can also be known. The hierarchy of scientific concepts enables them to learn the close connection between and the order of subordinate and superordinate concepts (Bart, 1976). Therefore, for post-learning to become hierarchical with pre-learning, the state of the students' knowledge is diagnosed, and the cause of the loss of knowledge is analyzed and dealt with. Teaching/learning and the students' level of concept hierarchy must be considered to handle the loss (Yoon & Kim, 2010). There is a theory of

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knowledge space for analyzing students' concept hierarchy (Kim *et al*., 2007; Park *et al*., 2005; Park, 2010; Byun et al., 2004). This theory is based on the hierarchy of knowledge claimed by Jean-Paul Doignon and Jean-Claude Falmagne (1999) and is a great way to analyze the state of students' knowledge and students' concept hierarchy.

The main purpose of evaluation in the course of teaching and learning is to determine the degree of learning of the learners. The distribution of the learners' right answers to the evaluation questions enables teachers to analyze not only the information about the individual learners' degree of learning but also the results of the collective evaluation of many students, and to determine the hierarchy of the learning contents. Inferring the information about the entire knowledge related to the evaluation from the fragmentary information obtained from the individual learners' right-answer questions is referred to as the knowledge space theory (Institute of Science Education, Kongju National University, 2000). In most of the evaluations in science education, the students' right-answer questions are classified into several types, and if there are certain relationships among the background knowledge items needed to answer each question, the relationships will also appear in many students' answers. Inversely, in this research, it is possible to analyze the system of knowledge related to each question using the results of the student evaluation, and the theoretical basis of this is the knowledge space theory (Institute of Science Education, Kongju National University, 2002). When the evaluation results are analyzed, the reliability of the analysis results depends on how sincerely the students responded to the evaluation tool. If a student assumes an insincere attitude towards the evaluation, the information about the student obtained from the evaluation results cannot be said to be true. As such, for all the students answering the evaluation tool, the followingtwo conditions are to be assumed. First, there is no case in which a student will correctly answer a question he or she does not know the right answer to by chance. Second, there is no case in which a student will wrongly answer a question that he or she knows the right answer to by mistake. If the evaluation tool is one that guarantees these two assumptions, it can be said to be an ideal evaluation tool, but such a case cannot be expected in real-life situations. Thus, to address this problem, a method in which only the answers that satisfy these two prerequisites will be used for the evaluation can be chosen (Institute of Science Education, Kongju National University, 2002). All the evaluation questions dealt with in this study are dichotomous questions that can be answered as "true" and "false," and the set of questions that a student answered correctly is referred to as the student's knowledge state. This set has knowledge information about the student, and if a sufficient number of students were evaluated with the same evaluation questions, the current knowledge level of the student can be known by comparing his/her knowledge state with those of the other students. This information was set as the criterion of a student's knowledge level to objectify it to the maximum. This is because no matter how many students participated in the evaluation, the individual students' answers can be classified into a certain number of types. Thus, if the number of students who participated in the evaluation exceeds a certain number, the types and number of knowledge state are expected to be definite. As such, the entire set of knowledge states in a certain evaluation can generally be said to be determined primarily.

It is very appropriate to arrange subjects such as mathematics and science in a hierarchy. Scientific Education Laboratory in Kongju National University (2002) suggested that when analyzing evaluation results, the students' hierarchies be measured according to whether the students were able to answer the evaluation items or not rather than using the students' grades. It also suggested that mistakes like leveling the grades be avoided.

There was an earlier study that used the theory of knowledge space and the knowledge state analysis method as evaluation tools. Kim *et al.*, (2007) developed questions about frictional electricity and applied it to the students in second year middle school. As a result, the students' knowledge state after studying the lesson can be determined by comparing the knowledge states of those who did not see and those who saw the structure of the scientific concept. Student learning can be diagnosed before and after the lesson presentation. Preliminary physics teachers analyzed the hierarchy of physical concepts by grade using the knowledge state analysis method and the theory of knowledge space. Park *et al.* (2005) analyzed the evaluation results and applied them to the efficient curriculum as the basic materials in physics education. With the knowledge state theory, Park (2010) analyzed the state of students' knowledge of physics, particularly about power and movement, in the Gifted Science Education Institute managed by a university. From this, he schematized the hierarchy of the concepts of power and movement and used such hierarchy to improve the teaching method of the concept,as basic materials in physics education. Kim *et al.*, (2011) classified high school students' science knowledge in the lesson on current and voltage, and developed evaluation questions on physics with the knowledge state theory. From this, they schematized the hierarchy of high school students' knowledge states and analyzed each individual's hierarchy. This has been a milestone for individualized learning.

These earlier studies schematized the hierarchy of knowledge as a method of analyzing students' evaluation results. The hierarchy of the middle school students' knowledge state of light, however, has not yet been studied. According to a study that analyzed the appropriateness of the middle school science curriculum, the lesson about light is one of the most difficult lessons for the students in physics (Lee *et al.*, 2006).

Therefore, in this study, the middle school students' knowledge state was analyzed using the theory of knowledge space. By schematizing the hierarchy of knowledge states based on this, an attempt was made not only to grasp the middle school students' knowledge state on light but also to apply it as the basic material for improving the method of teaching such knowledge item. To achieve the purpose of the study, evaluation questions on light were first developed and applied to middle school students, and then the results of the evaluation of the students' knowledge state on light were analyzed. Lastly, the hierarchy of the questions and the individuals' knowledge states were analyzed.

Ⅱ. Methods

1. Participants

Thirty middle school students who listened to an online science lecture for the gifted managed by Gifted Science Education Institute were evaluated to analyze their concept of light. The middle school was located at K University in a city of Chungcheongnam-do Province. The education course is divided into an online lecture and a camp, and aims to self-initiate the students. For the selection of study subjects, the students first applied for participation in the study based on the school principal's recommendations. The study subjects were selected by examining the student applicants' career papers. The final successful candidates joined the homepage of Gifted Science Education Institute in K University, and their qualifications were examined. Thereafter, they were accepted in the online education. There were 136 applicants in all. The students were made to participate in an entrance ceremony and to undergo a seven-day orientation, after which they were educated online for 12 weeks in the first semester. The candidates were selected upon their completion of the formative evaluation and homework. The candidates stayed in the camp for training for two nights and three days, during their summer vacation. The candidates who finished the camp training took the online course for 12 weeks in the second semester, after which the final selection was made. Even though the final candidates were selected, the course was considered not completed if the student fell short of the standard of Gifted Science Education Institute. The completion conditions were as follows: (1) the candidates were selected through comprehensive online evaluation in the first semester, and had to join camp training during their vacation and (2) the candidates had to take the online course for more than two thirds of the first and second semesters, and had to do more than 70% of the homework online. There were 66 students who stayed at the camp for training during their vacation. Of these, 36 students who either did not complete the program course or did not answer the questions sincerely when they participated in the evaluation question examination were excluded from the study, and the remaining 30 students' answers to the evaluation questions were analyzed.

2. Evaluation Questions

The evaluation criteria were presented before the formulation of evaluation questions about light based on the contents of the science curriculum. First, the science knowledge items were classified into three areas (facts, concepts, and laws/principles), referring to the criteria for the classification of the National Evaluation System Development of Science Knowledge (Kwon *et al.*, 1998),and the hierarchy of evaluation questions was analyzed. The questions were formulated in sets of five multiple choice items, and the time for answering all of them was limited to one hour. A physics education expert and two science teachers modified and supplemented the questions five times, through pilot tests. After checking the validity of the questions, a 15-item objective test was finally developed. Table 1 shows the areas and contents of the questions.

The aforementioned questions were applied to 30 middle school students, and the results were arranged into a hierarchy using MS Office 2007 Excel Macro and VBA (Visual Basic Application). The knowledge states of the individuals and the group were analyzed. The process of analyzing the evaluation questions, which was the purpose of this study, was not directly related to the questions' concrete contents as the authors were interested only in analyzing the students' indirect responses (Byun *et al.*, 2004).

Ⅲ. Results and Discussion

In this study, the concept of light of the middle school students who listened to the online science lecture in Gifted Science Education Institute in K University was analyzed. Also analyzed were the evaluation results of the 30 students in a class, and through individual sampling, the hierarchy relations of the questions were examined. The individuals and the group were diagnosed based on such hierarchy relations.

In this study, the hierarchical analysis process on the concept of light, quoting Byeon Du-won *et al.*'s (2004) analytical method, was analyzed using MS Office Excel Macro and VBA. The analytical process of the hierarchy that this study aimed at was not directly related to the concrete contents of the evaluation questions, but it should be noted that these contents were made the bases of the analysis of the students' indirect reactions. The results of the processing of the data obtained from the analysis using MS Office Excel Macro and VBA are as follows:

(1) Assessment data input: The data were recorded using the Microsoft Excel program (a score of 1 was given for the correct answer, and 0 for a wrong answer).

Table 1

Light concept evaluation question areas and contents

Question	Concept Area	Science Knowledge Area	Question Content
1	Reflection of light	Fact	Shape of a letter reflected on a mirror
2	Reflection of light	Law/principle	A phenomenon involving the incidence of light on a mirror
3	Reflection of light	Law/principle	Rotation of light reflected on a mirror when passing a point
4	Refraction of light	Concept	Phenomenon of the refraction of light
5	Refraction of light	Concept	A phenomenon involving light passing from air to water
6	Refraction of light	Concept	Explains the movement of water waves passing from a point to another
7	Refraction of light	Law/principle	An incidence angle and a refraction angle of light given incidence obliquely on the boundary surface from air to glass
8	Dispersion of light	Law/principle	The most refracted rainbow colors passing through a prism
9	Dispersion of light	Concept	Why light is broken into different colors by waterdrops and a prism
10	Reflection, refraction, & dispersion of light	Fact	The refraction and reflection of light in a waterdrop when a rainbow is formed
11	Reflection of light	Concept	Why a yellow flower is seen by people as yellow
12	Interference of light	Fact	Shape of the reflected waves' surface after water waves head towards a vertical obstruction
13	Interference of light	Fact	Shape of water waves reflected on a wall when a finger is dipped into a washbowl
14	Diffraction of light	Concept	Phenomenon of diffraction of sound
15	Diffraction of light	Concept	When playing hide-and-seek, how one can hear while hiding

(2) Selection of knowledge state: This is the most critical phase in the application of the knowledge space theory as inaccurate results due to a student's insincere attitude towards the assessment will have a great impact on the results of the other students. Thus, it had to be ensured that only the answer sheets satisfying the two premises earlier specified would be used for data processing. In this case, it was supposed that all the answer sheets conformed with the requirement that all the students sincerely answered the evaluation questions.

(3) Analysis of hierarchy: Based on the hierarchical analysis earlier described, a hierarchy was found between two items selected at random.

(4) Hasse data: Still, there were too many inconvenient elements to come up with a hierarchy, even though all the components of the hierarchy were recognized to have been between the two items selected at random. For instance, suppose that there exist "ab," "bc," and "ac" relations for items "a," "b," and "c" ("a" refers to a group of students giving correct answers only to "a," and "ab" refers to a group of students who gave correct answers to both "a" and "b." Relations "ab" and "bc" are good enough to represent the sequence, but relation "ac" created some difficulty in coming up with a

hierarchy. Thus, the simplified data were processed by excluding the transitive relations from the sequential relations.

(5) Drawing a hierarchy: The Hasse data obtained in phase D were drawn on a plane, which is called a "Hasse diagram."

1. Analysis and diagnosis of the students' knowledge states

Fig. 2 shows the evaluation results of the 30 students in the class. The dotted-line boxes show how connected the questions are in the hierarchy. The students' knowledge states were classified into three hierarchy groups: those on the reflection of light, those on the dispersion of light, and those on the diffraction of light. As the hierarchy of diffraction is not yet being systematically taught in the current curriculum, it was not included in this study.

When the states of the students' knowledge of light formed hierarchy relations, hierarchy relations were found among questions 10-1-11-2 and 10-9-8. Most of the students gave the correct answer to question 10 because it is at the bottomof the hierarchy. In the hierarchy of questions 10-1-11-2, question 10 is the fact area about the refraction, reflection, and dispersion of light in a waterdrop when a rainbow is formed. Question 1 is the concept area about the shape of a letter reflected on a mirror, and question 11 is the concept area about why a yellow flower is seen as yellow. Question 2 is the law/principal area about the phenomenon of light producing images on a mirror. When light is reflected on a mirror, how a reflection occurs can be explained

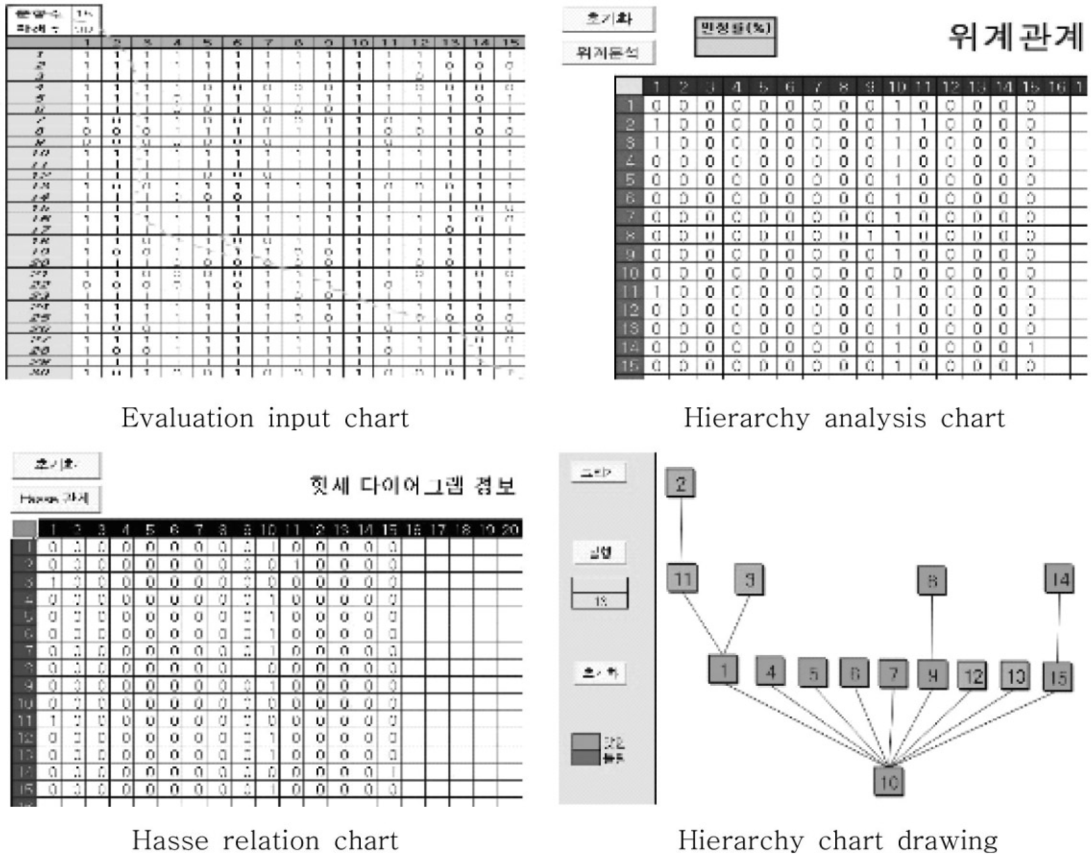


Fig. 1 *Knowledge state hierarchy drawing analysis process using the program*

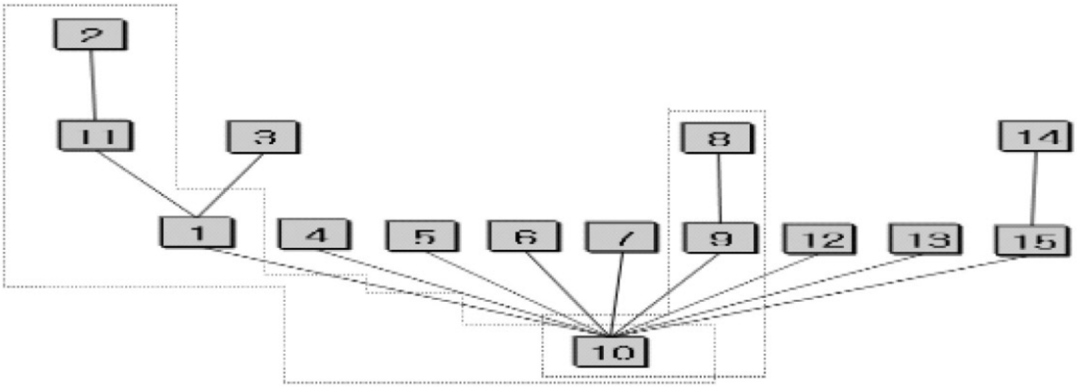


Fig. 2 *Analysis of middle school students' knowledge states*

with the boundary conditions of the medium from Fermat's principle of least time, Huygen's principle, Maxwell's equations, and others. With Fermat's principle of least time, which explains how light travels in a route that takes the least time, the travel route of reflective light was examined. That is, the light reflected on a mirror reflects the same incidence angle, and the reflective light is on a coplanar line with the incidence light and normal light. The students had to give the correct answer to questions 10−1−11 to be regarded as having given the correct answer to question 2. Questions 10−1−11 are all about the reflection of light, thus requiring that such concept first be understood. In the hierarchy of questions 10−1−11−2, question 1 is ranked above 10. Question 1 is about the shape of a letter reflected on a mirror, and the fact that its distance from a plane mirror to its reflection is the same as that from a mirror to the object itself. The size of the reflection is the same as that of the object,and its left and right parts are changed. Each ray of incident light is reflected on a mirror and enters the eyes. Question 1 is ranked above question 11, which is about why a yellow flower is seen as yellow. The colors of the objects seen by people are the colors of the light reflected on or penetrating the objects among the many colors of the objects. The objects appear to have specific colors because the light emitted or reflected by the object is limited to a specific wavelength area, and the optic nerves recognize it. Some students, however, thought that the colors of objects change not due to the light source or its interaction with the object but due to specific qualities of the objects. In the hierarchy of questions 10−9−8, questions 9 and 8 are ranked above question 10, which is about the refraction, reflection,and dispersion of light in a waterdrop, as explained earlier, and questions 9 and 8 are about the dispersion of light. Question 9 is the concept area about why light is broken into different colors by a waterdrop and a prism. Question 8 is the law/principal area about which colors refract the most when rainbow colors pass through a prism. Generally, the shorter the wavelength is, the slower the speed of light is. The refractive index of a medium depends on the wavelength, and purple light's short wavelength is higher than red's. Therefore, purple is the most refractive and red is the least refractive. Through questions 10−9−8, such principle can be known.

The results of the concept of light of 30 middle school students from Gifted Science Education Institute in K University were analyzed. It was seen that there were hierarchy relations among the questions on the reflection of light (questions 10−1−11−2] and among those on the dispersion of light (questions 10−9−8]. According to the science knowledge area of the above hierarchy groups, the structure of the fact−concept−principle/law can be seen from underneath, and the students found the principle-related questions the most difficult.

2. Analysis and Diagnosis of the Students' Knowledge States

In this study, how 30 students' knowledge states were distributed in the above analysis was examined. There are typical examples below one of them with the students' information. When the hierarchy was analyzed using the knowledge space theory, the hierarchy and knowledge state not only of the group but also of the individuals in the group were determined. Fig. 3 shows the analysis results of student A's knowledge state. The square represents the correct answer and the diamond a wrong one.

Student A showed no hierarchy of questions and no concept of the reflection and dispersion of light, and there was a low connection between the questions. That is, student A had no hierarchy of knowledge states on the reflection and dispersion of light, and no concept of light. Thus, systematic individualized education about the concept is required for this student, by analyzing the student's knowledge state of light.

As shown in Fig. 4, student B had the fullest grasp of the concept presented in the questions.

Student B got the right answers to the connective questions on the reflection of light (questions 10-1-11-2) and to those on the dispersion of light (questions 10-9-8). Therefore, student B had a systematic hierarchy of the concepts of the reflection and dispersion of light,

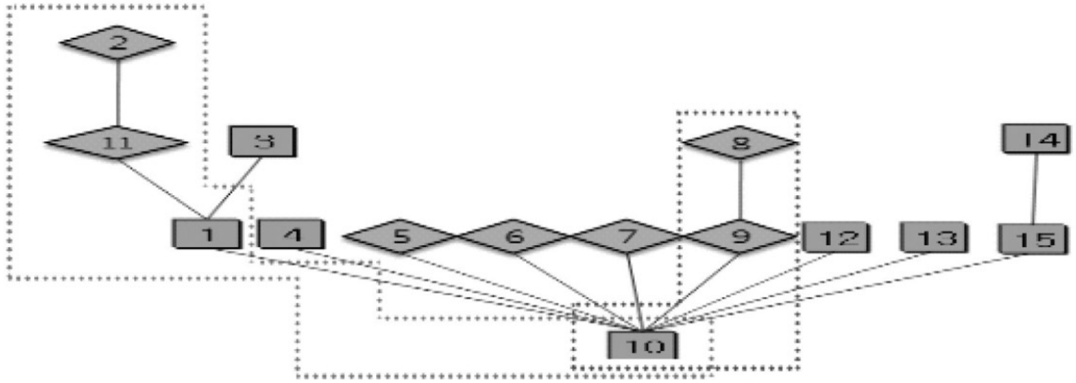


Fig. 3 *Knowledge state of student A*

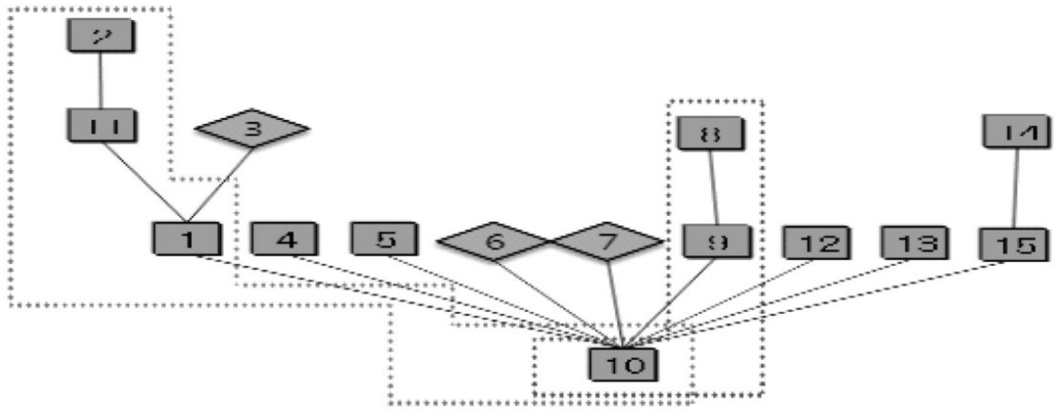
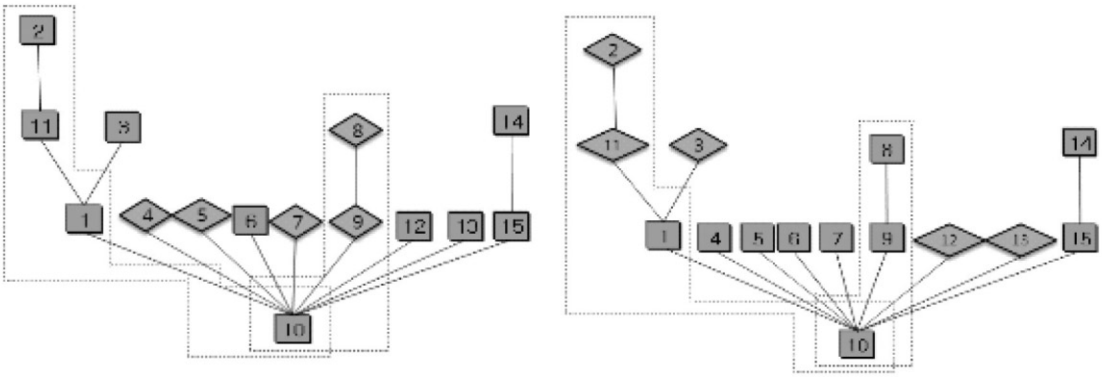


Fig. 4 *Knowledge state of student B*



(a) Knowledge state of student C (b) Knowledge state of student D

Fig. 5 *Analysis of the knowledge states of the students who got the same scores*

and had the fullest grasp of the concept of light.

Fig. 5 is the hierarchy of the students who obtained the same scores. Students C and D had a good grasp of the concepts presented in the questions the students were made to answer in this study. On the other hand, even though such students obtained the same scores, each individual had a different knowledge structure and has to be evaluated differently.

It was diagnosed that while student C had a hierarchy of knowledge states on the reflection of light (questions 10−1−11−2), he/she had no hierarchy of knowledge states on the dispersion of light (questions 10−9−8). In contrast, while student D had a hierarchy of knowledge states on the dispersion of light (questions 10−9−8), he/she had no hierarchy of knowledge states on the reflection of light (questions 10−1−11−2).

As can be seen, the two students who got the same score had different diagnosis results, and it is hard to analyze the existing general evaluation results based on the scores. There was a slight difference, but the hierarchy of knowledge states was divided into the two groups that had a great hierarchy and none, respectively. Although only the analysis results of four students (those who showed a great hierarchy and those who showed none but who got the same scores) were presented herein, all the 30 students who joined this study were actually diagnosed based on their individual evaluation results. Had the results of the student evaluation been diagnosed and compared with those of the existing method in the field of education, they would have been regarded as being on the same level of science knowledge as the scores, ignoring the individual differences. Also, the next step − teaching and learning the wrong concept that has not been dealt with − would have proceeded.

Consequently, the results of the analysis of the individual knowledge states using the knowledge space theory show which students had the wrong concepts in an area, and are expected to play the role of guiding how to teach and learn the subject matter of light in the future (Park, 2010).

Ⅳ. Conclusion and Suggestions

Evaluation questions were developed to analyze the middle school students' knowledge states about the concept of light, and the grouped students' hierarchy of knowledge states in relation to such questions was compared with that of the individual students by applying the questions to them. It was known that the students' concepts of the reflection, dispersion, and diffraction of light were not to be written, and that their knowledge states on these have been formed. By analyzing the students who were set up correctly on the hierarchy of knowledge states and those who were not, diagnosis was made and data were obtained about the students' individual knowledge states. In the results, while student A was set up correctly on the hierarchy of knowledge states about the reflection and dispersion of light, student B was not. Even though some of the students got the same scores on the questions on light, the hierarchies of their knowledge states were different. Students C and D got the same score, but student C was set up correctly on the hierarchy of knowledge states on the reflection of light but was not on the hierarchy of knowledge states on the dispersion of light. In contrast, although student D was not set up correctly on such, he/she was set up correctly on the hierarchy of knowledge states on the dispersion of light. In other words, even though some of the students got the same scores, individual students have different knowledge states and thus have to be evaluated differently. It was found that analyzing the knowledge states using the knowledge space theory enables learning about the relations of the questions (i.e., the hierarchy) and the individual knowledge states. It was also found that the hierarchy of knowledge states obtained from the analysis can be used as an evaluation tool for diagnosing the grouped and individuals' knowledge states.

It is essential to study the hierarchy of learners' various knowledge items, such as the systematization of teaching/learning, individualized learning, and setting up hierarchy relations. It is crucial to study the hierarchy of the lessons in the physics curriculum and what the students know about such lessons. It is hoped that this diagnosis using the knowledge space theory will be considered when planning the teaching method to be used and when evaluating the students' grasp of physics concepts other than light. Above all, a study should be conducted on how best to teach the hard physics lessons so that the students would understand them fully and so that the current teachers would know how to teach them accurately and effectively. It is also suggested that a qualitative research be conducted on why the students have the knowledge states that they have as well as a quantitative research to analyze individuals' knowledge states in greater detail.

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