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Paper Title: On Some Problems of How Learners' Knowledge is Interconnected in the Understanding of Scientific Concepts: A case study of the concept of "weight" and its related matters
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Abstract: However, it is rather obvious that not the whole problems of learning and teaching of science have been clarified so far. We still have a serious problem to be solved concerning the ways in which one's knowledge and concepts which he/she obtains from public school education are stored in his/her memory and what kind of such knowledge and concepts are maintained in his/her memory. The purpose of this study is to clarify how a certain newly obtained piece of knowledge and concept can be comprehended by the students in Japan before they study them at school and after a certain long time has since the first study of them. We can regard our problem as that of how the association pattern of knowledge in one's understanding can be changed by his/her learning activities. Osborne and Freyberg (1985) have pointed out the same problem. White (1990) and others (for example, Baird and Mitchell, 1986) have also pointed out the significance of the problem.

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ON SOME PROBLEMS OF HOW LEARNERS' KNOWLEDGE IS INTERCONNECTED IN THE UNDERSTANDING OF SCIENTIFIC CONCEPTS:
A case study of the concept of "weight" and its related matters

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INTRODUCTION

Recently, it has been made clear as a result of many studies of "misconception" that the learning and teaching of science have many difficult and subtle features. For example, we can name Osborne and Freyberg (1985), Driver, Guesne and Tiberghien (1985), West and Pines (1985), Millar (1989), White (1990), and so on.

However, it is rather obvious that not the whole problems of learning and teaching of science have been clarified so far. We still have a serious problem to be solved concerning the ways in which one's knowledge and concepts which he/she obtains from public school education are stored in his/her memory and what kind of such knowledge and concepts are maintained in his/her memory. The purpose of this study is to clarify how a certain newly obtained piece of knowledge and concept can be comprehended by the students in Japan before they study them at school and after a certain long time has since the first study of them. We cahow the association pattern of knowledge in one's understanding can be changed by his/her learning activities. Osborne and Freyberg (1985) have pointed out the same problem. White (1990) and others (for example, Baird and Mitchell, 1986) have also pointed out the significance of the problem.

The problem which has been pointed out by Osborne and Freyberg (1985) is the importance of children's ability to relate the new ideas that they construct through one or more related learning experiences to the old ideas that they already hold, to other experiences and events in the world around them and to those people whose views they value. In Osborne and Freyberg (1985), the learners' ideas that they already hold are not scientifically correct ones. However, it has been observed that even though the learner had an adequate prior piece of knowledge and concept concerning a certain matter, he/she may formulate a rather inadequate or incorrect concept concerning the same matter through “learning.” Osborne and Freyberg (1985) and White (1990) do not touch on this particular phenomenon.

In this study, the author clarifies the new facts that even though the learner had an adequate prior piece of knowledge and concept concerning a certain matter, he/she may formulate a rather inadequate or incorrect concept concerning the same matter through “learning.” This new observation is different from Osborne and Freyberg (1985). In addition, the author explains based on his observations of some related specific phenomena why the association pattern of knowledge is important. His observations are summarized as follows:

First, to learn a new scientific concept does not always promote a better understanding of the concept.

Secondly, with respect to some scientific concepts, more middle school students have correct ideas before learning than university students who have already studied them.

Thirdly, it seems to be the case that this problem can be attributed to the organization of lessons in which teachers do not take the learners’ prior knowledge and concepts into consideration. In other words, the teachers could not polish up the learners’ naive prior knowledge and concept to better scientific one.

Fourthly, one of the most important thing to achieve in learning is the learners’ prior knowledge and concepts to be adequately interconnected to new knowledge and concepts. That is to say, to understand the scientific concept adequately, the association patterns of one’s knowledge ought to be interconnected.

It is said that the Japanese students rank higher than many other countries in achievement tests, for example; IEA (The International Association for the Evaluation of Educational Achievement, 1988), Rosier and Keeves (1991), Postlethwaite and Wiley (1992), Keeves (1992). This study also tries to make it clear that the Japanese students’ achievement is not necessarily satisfactory in terms of quality.

1 THE PURPOSE OF THIS STUDY

1.1 To clarify how Japanese national teachers college students and seventh graders understand the concept of "weight" and its related matters.

1.2 To clarify the process of the students' developing inadequate or incorrect ideas in understanding of the concept of "weight" and its related matters.

1.3 To clarify how the students' ideas change between before and after the experiment conducted by the author after the investigation through the questionnaires. In other words, to demonstrate how different the students' ideas become between the classes which only performed the experiment and the classes which carried out the experiment and gave the explanation.

1.4 To point out the problems of the learning of science, based upon the comparison between before (= the middle school students) and after (= the college students) the learning, upon the investigation of what processes there are to have the students make mistakes and upon the change of students after the instruction.

2 THE PROCEDURES OF THIS STUDY

2.1 The subjects for this study

The author conducted a survey among 149 seventh graders of four classes (= 12-year-old middle school students) and 107 college sophomore students in Japan. Both are considered to be average Japanese students. The middle school is a municipal one and the university is a national one.

The two classes out of the four in the middle school are given the experiments and the explanation, the other classes only the experiments.

It is the following reason why the college students are chosen as subjects.

First, it is extremely difficult to examine how one person diachronically acquires a certain concept during the time from an elementary school to university.

Secondly, to investigate what is stored by many university students in the long-term memory can provide an indirect clue to when the elementary and middle school students acquire the same single concept in the learning and teaching of science.

Thirdly, it is convenient to analyze the answers by the university students who are said to be “articulate novices (Resnick, 1987)” as they can express their own reasons to the question. But the middle school students can not express their own ideas as well as the university students, as is often the case with them.

It is said that about 5 out of 200 (= approximately the number of students in one grade) middle school students can pass an entrance examination to this university (faculty of education) after high school.

2.2 The Questionnaire which is used in this study

In this study, there are two questions (Question 1 and Question 2) to be asked. Question 1 is concerning the concept of “weight” and its related matters. Question 2 is asked after Question 1 is answered and the phenomena which Question 1 asked about are demonstrated or explained.

(Question 1)

The question 1 which is asked in this study is shown by Figure 1. The author referred to “Physics Education (1990),” when he made this question.

The same question is asked of the middle school students and the university students. Both students have learned the contents of the textbooks which are based on the same course of study. But the textbooks that those students have used are not the same.

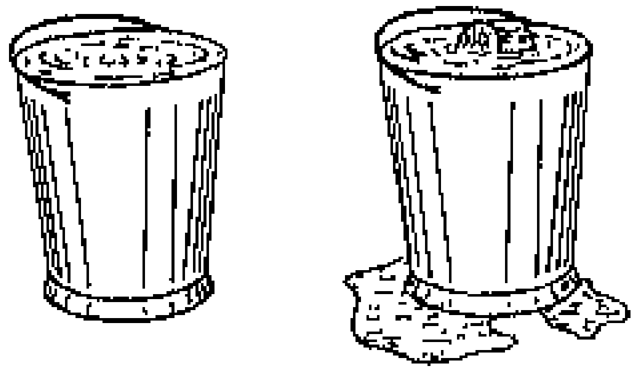
In this survey question, the author had the subjects express the reasons why they selected their answers. Because their reasons give us the clues to clarify what makes them acquire inadequate or incorrect concepts.

The contents of the explanation are as follows;

- The water overflows when a wooden block is put into one of the buckets.
- The weight of the overflowed water is equal to that of a wooden block (shown by the experiment).
- When an object floats on the water, the weight of the object is the same as that of the water that it displaces (Archimédes’ prínciple).

By the way, this explanation is given by the author with the same contents and method to both students.

There are the two identical buckets which are filled with water. When a wooden block is put into one of the buckets, the water overflows from it, as is shown in the picture below.



If the weight of the overflowed water is not taken into account, which is heavier, the bucket that contains only water or the bucket that the wooden block is floating in; or are they the same weight? Select the item that you think is the best among the following options. Then, explain as fully as possible why you have selected your answer.

(A) The bucket which the wooden block floating in is lighter.
(B) Both buckets are the same weight.
(C) The bucket which the wooden block floating in is heavier.
(D) I do not understand.

Your answer. Explain why you think so.

______________ ________________________________

Figure 1 Survey question (Question 1) about the concept of "weight" and its related matters.

(Question 2)

Immediately after the end of the Question 1, an experiment was conducted by the author to illustrate the content of Question 1. Then, he investigated how the subjects' prior knowledge and concepts would change. The contents of Question 2 are to investigate the subjects' change. To avoid redundancy, Question 2 is shown in the left-hand section of Table 2 in the results of 3. 2. 1 of this study.

3 THE RESULTS OF THIS STUDY

3.1 The results of Question 1

3.1.1 The answers selected by the subjects

The results as to which answers are selected by the students are shown by Figure 2. They are very interesting because the percentage of the incorrect answer “(A) the wooden block floating in is lighter” by the university students, is about 1.7 times more than the middle school students. And the more interesting thing to us is that the percentage of the correct answers, “(B) both buckets are the same weight” by the middle school students, is about 1.7 times more than the university students. In addition, the percentage of the incorrect answer, “(C) the wooden block floating in is heavier” by both students, is almost the same.

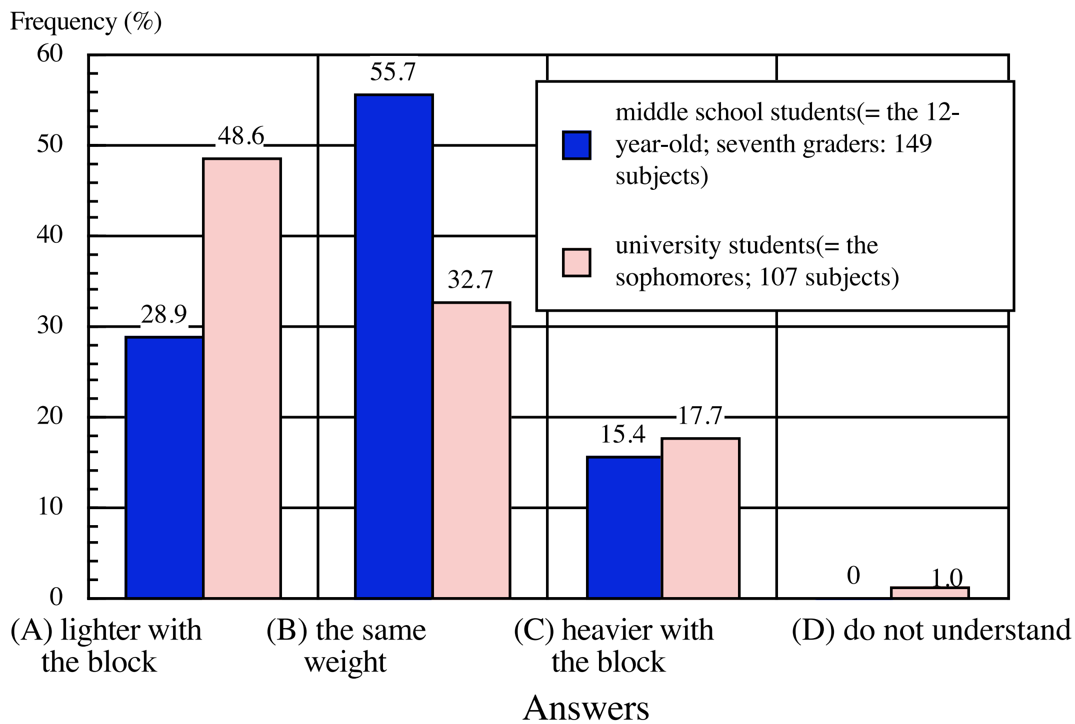


Figure 2 The frequency of each answer among the middle school students and the university students

3.1.2 The reasons why the students select each answer

Now let us examine the reasons why the students select each answers. Because it is very important to find out how the students' knowledge is interconnected in the understanding of the concept of "weight" and its related matters.

Those reasons are shown by Table 1-1, 1-2. The percentage of each Table is the rate by which the options of Question 1 are selected. From the results of Table 1-1, 1-2, the following three facts become clear.

First, the explanation of the reason why the students select their answers, if it is compared between the middle school students and the university students, shows a marked difference as to whether they use technical terms or not. For example, the university students use the terms "density," "buoyancy," "volume," "mass," and so on, but on the other hand, the middle school students do not use them. It seems that this difference mainly depends on as a result of whether they learn the terms or not.

Secondly, about 80% of the middle school students who select the correct options can explain the reason properly, but on the other hand only about 51% of the university students who

Table 1-1 The reasons why the middle school students select each answer (%)

Answers	The reasons why the middle school students select each answer	Response percentage
(A)	Because wood is lighter than water.	62.7
	Because the water overflows.	16.3
	Because the wooden block is floating on the water, the total weight of the wooden block does not add to the water. (Because the wooden block is floating on the water, we do not take the weight below the surface of the water into account.)	11.7
	Because the wooden block absorbs water and it is heavier than before, so the volume of the water gets smaller.	4.7
	Because the water pushes the light weight of wood up, so the weight of the wood below the surface disappear.	2.3
	Because wood absorbs water and assimilates carbon dioxide.	2.3
(B)	Because the same volume of the water as the volume of the wooden block overflows.	79.7
	Because the same volume of the water as the volume of the wooden block overflows.	7.1
	It is the same weight because the wooden block is floating, even though the water overflows.	3.6
	Because a body bears no relation to the weight when it is floating on the water.	3.6
	Because there is the weight of the wooden block.	1.2
	Because the wooden block is floating on the water.	1.2
	Because the wooden block absorbs water.	1.2
	Because the same quantity of water remains.	1.2
	Because the water overflows.	1.2

	Because it is heavier with the wooden block above the surface of the water.	43.5
(C)	Because the wooden block is heavier than the overflowed water.	30.4
	Because the bucket is heavier with the wooden block.	21.8
	Because the wooden block absorbs water.	4.3

(Notes) 1. Answer (A) : "The bucket which the wooden block floating in is lighter."
Answer (B) : "Both buckets are the same weight."
Answer (C) : "The bucket which the wooden block floating in is heavier."
Answer (D) is eliminated. Because no one selects the answer among the middle school students.
2. The percentage in Table 1-1 shows the rate of each answer.

Table 1-2 The reasons why the university students select each answer (%)

Answers	The reasons why the university students select each answer	Response percentage
	Because the amount of overflowed the water is the same as the wooden block which is in the water and the density of the wood is smaller than the water, the overflowed water is heavier.	64.2
	Because the wooden block is affected by the buoyancy and the volume of the overflowed water is the same as that of the wooden block.	11.3
	Because the weight of the wooden block becomes zero, and the block is weightless and is floating. The block is floating because of buoyancy and has no relation to the weight.	7.5
(A)	Because volume and mass differ from matter to matter they are two different things.	3.8
	Because if the water does not overflow the weight of both buckets is the same, the bucket in which the wooden block is floating is lighter.	3.8

	Because the volume of the overflowed water is larger than that of wooden block.	1.9
	I do not understand well. I do not know the reason. I have a feeling that this is correct.	7.5
(B)	Because the weight of the wooden block is the same as that of the overflowed water.	51.2
	Because the quantity of the overflowed water is the same as the volume of the wooden block.	11.6
	Because the volume of the overflowed water is the same as that of the wooden block.	7.0
	Because the upward and downward forces on the wooden block are in a balanced relation to one another.	7.0
	Because the addition of the weight of the wooden block means that the weight of the overflowed water is reduced.	2.3
	Though the weight of the wooden block is lighter than that of the overflowed water, the weight of the wooden block above the surface of the water balances the total weight.	2.3
	Because the wooden block is floating above the surface of the water.	2.3
	I do not know the reason. Because the wooden block is floating in the water. I chose this by a process of elimination.	16.3
(C)	Because the wooden block above the surface of the water is heavier.	72.7
	Because the overflowed water is equal to the volume of the wooden block and the density of the wooden block is larger than that of water.	9.1
	Because the overflowed water is equal to that of the wooden block and the density of the wooden block is smaller than that of water.	4.5
	Because the buoyancy acts on the wooden block, it is lighter than that of its real weight. And the overflowed water is not so much as the real weight.	4.5
	I do not understand. The problem is what the relation between the overflowed water and the mass of the wooden block is.	9.2

(Notes) 1. Answer (A): "The bucket which the wooden block floating in is lighter."

Answer (B): "Both buckets are the same weight."

Answer (C): "The bucket which the wooden block floating in is heavier."

Answer (D) is eliminated. Because only one select the answer among the university students.

2. The percentage in Table 1-2 shows the rate of each answer.

select the correct options can explain the reason properly. In short, in addition to the fact that the percentage of the correct answers by the middle school students is about 1.7 times better than the university students, there are more middle school students who can explain the reason properly than university students.

Thirdly, these explanations of the reasons show that the reason why the university students select the incorrect answer has much to do with their learning of the concepts of "density" and "buoyancy."

3.2 The results of Question 2

3.2.1 The degrees of the changes of the learners' ideas

The results of Question 2 are shown in Table 2. From the results of Table 2, the following facts are clear.

First, as a general trend, the university students' ideas are more difficult to change than those of middle school students'. We can assure this fact from the following observation. Because the

Table 2 The changes of the learners' ideas after the experiment and explanation(%)

The degree of the changes of the learners' ideas	the middle school students		the university students
	experiment only	experiment with explanation	experiment with explanation
(a) I have not changed my idea because I made the choice "(B) the same weight" from the start. I can explain it accurately.	41.3	54.1	26.2

(b) I have changed my idea although I made the choice "(A) with the block is lighter" (or "(C) with the block is heavier") from the start. I can explain it accurately.	12.0	12.2	14.0
(c) I have not changed my idea because I made the choice "(B) the same weight" from the start. But I can't explain it well.	10.7	5.2	4.7
(d) I have changed my idea although I made the choice "(A) with the block is lighter" (or "(C) with the block is heavier"). But I can't explain it well.	16.0	12.2	17.8
(e) I believe the result of the experiment, but my idea does not change "(A) with the block is lighter" (or "(C) with the block is heavier").	12.0	6.8	31.8
(f) I do not believe the result of the experiment, and my idea does not change "(A) with the block is lighter" (or "(C) with the block is heavier").	2.7	0	0.8
(g) I am confused by the experiment and the explanation. I do not understand.	5.3	9.5	4.7

(Notes) 1. "Experiment only" means that the subjects are asked about how their ideas have changed after they watched the experiment.
2. "Experiment with explanation" means that the subjects are asked about how their ideas have changed after they watched the experiment and they were given the explanation by the author.

percentage of the item "(c) I believe the result of the experiment, but my idea does not change" by the university students is about 2.7 times more than the middle school students except for those the middle students who saw only the experiment.

Secondly, there are about 12-14% of both middle school and university students who can change their ideas after they saw the experiment and heard the explanation about the contents of it, although they did not have correct ideas originally. This means that there are few who can change their ideas even after they watch the experiments and hear the explanations.

Thirdly, among the middle school and university students who think correctly at first or change their ideas correctly after the experiments and explanations, there are many students who can not explain the phenomena appropriately yet. And between those middle school students who watch only the experiments and those who hear the explanation after they watch the experiments, the number of those among the latter who can not explain the phenomena correctly decreases by about 10%. So, this result shows that it is desirable to give an explanation for the phenomena after experiments.

Fourthly, a few students are thrown into confusion even after they watch experiments and hear explanations. Especially, in that case there are more middle school students who are thrown into confusion than university students after they hear explanations. But the greater part of students understand more deeply after they hear explanations.

4 DISCUSSIONS AND IMPLICATIONS FOR THE TEACHING AND LEARNING OF SCIENCE

The above mentioned results remind us of Rousseau's *Emile*. We find the following in the famous opening paragraph of the book: "Everything is good as it leaves the hands of the Author of things; everything degenerates in the hands of man (from the translation by Bloom, 1991)."

The meaning of this passage does not necessarily deny the importance of education, though the author cannot elaborate on this point in detail owing to limited space. That applies to the results of this paper, too. The author wants to interpret the results of this paper, if anything, as evidence to show more importance of education and learning than ever. Because though there are more middle school students who can choose correct answers and say the reasons appropriately than the university students, we cannot say that the middle school students have better comprehension about the concept of "buoyancy," "density" and so on. To thoroughly understand or to correct the misconceptions, if anything, it is really necessary for most students to receive education and learn.

4.1 The university students come up with more misconceptions than the middle school students by the learning of some concepts

Now, the author shall examine the results of this study more carefully. To begin with, let

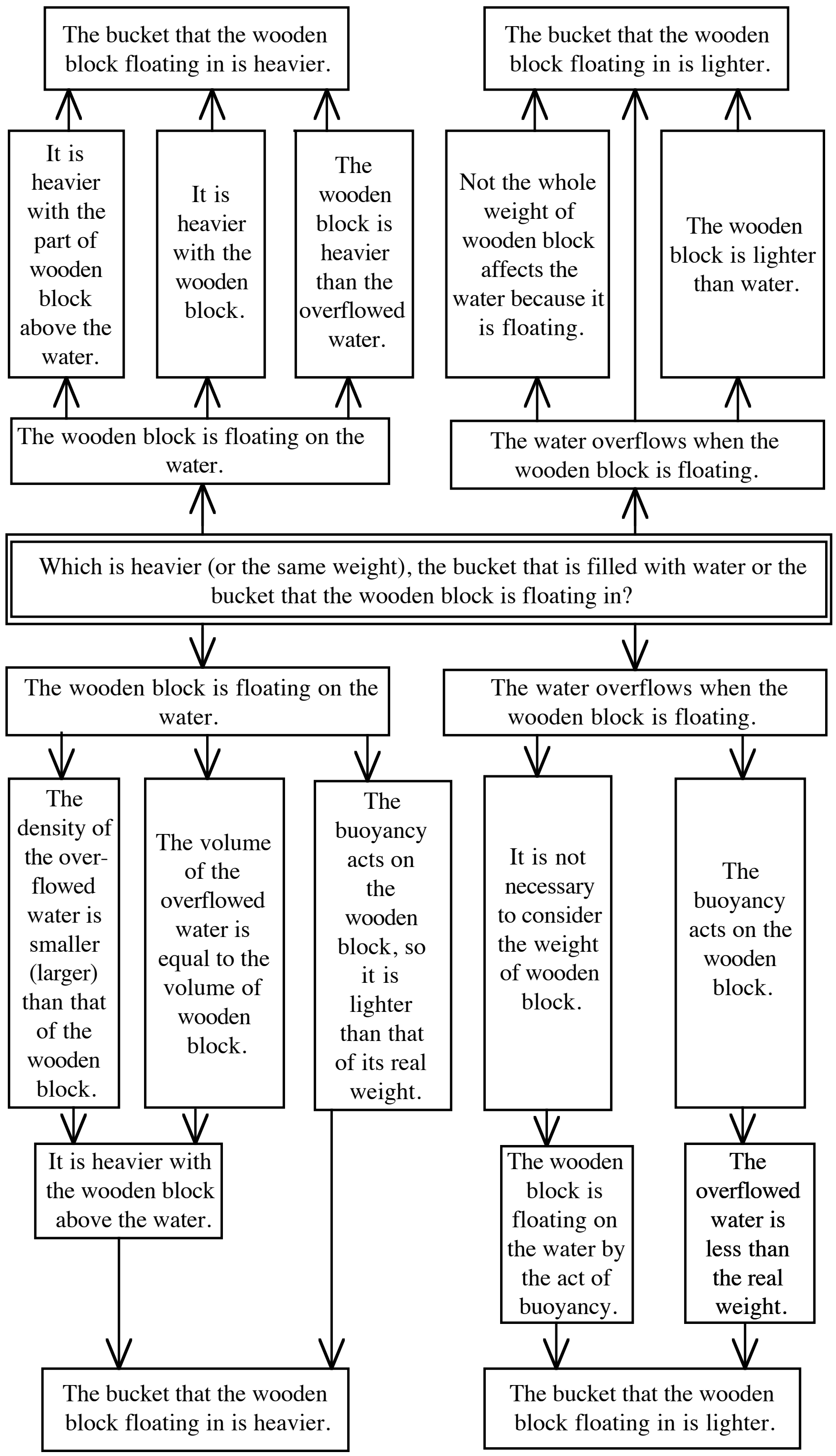


Figure 3 A flowchart showing the difference between the middle school students' and the university students' ways of thinking in which the

reason are not correct (↑ indicates the thought flows of the middle school students, ↓ indicates the thought flows of the university students)

us analyze Tables 1-1 and 1-2 more carefully. The author classifies the reasons which are not correct in Figure 3.

Figure 3 shows that a fundamental pattern of incorrect reasoning has similarity between the middle school students and the university students. Both students pay attention at first to the wooden block that is floating on the water and the overflowed water when they solve the problem. A very serious difference between both students is the next thinking process. As previously stated, the university students use the terms "buoyancy," "density," and so on, to explain the their reasons. However the middle school students do not use those terms to explain the phenomenon. That is to say, whether they use those terms or not mainly depends on whether they have leaned them or not. That is why many university students make mistakes.

Is that all the reason why they make mistake? The other reason they can not answer correctly is because they merely understand the terms superficially. In short, they do not grasp the terms as the concepts that have connotations and denotations. Moreover they have not learned about when, where and how the terms are used. Especially they have not learned them just once and within limited contexts of the concept of "buoyancy" in elementary and secondary education of Japan. It is a very serious problem that the learner's adequate prior knowledge and concept, however naive they may be, change to inadequate or incorrect knowledge and concept, and this change has much to do with his/her learning of the concept of "buoyancy," and what is worse, the Japanese students learn the contents only one time.

Another problems is that the teacher can not polish up the learner's naive prior knowledge and concept to a better scientific one, despite his/her efforts. These facts mean that education and learning are more than simple addition of propositions to memory, and that teaching for deep understanding is a more difficult and subtle task than merely setting out facts clearly and checking what they absorb.

4.2 One of the most important things in learning is how a learner's knowledge is interconnected in understanding

From these discussions, the author thinks that one of the most important things in learning to understand the scientific concept adequately is that the patterns of one's knowledge ought to be interconnected. In short, in order to understand a scientific concept appropriately or correctly it is necessary to interconnect the learner's prior knowledge or concept, whether it is correct or not, with the concept which is acquired through learning. Special emphasis should be placed on this necessity when students already have correct ideas before learning.

Up until now, "children's science" and its consequences for learning and teaching have pointed out and classified the patterns of outcomes of teaching and learning (Gilbert, Osborne and Fensham, 1986), but the point under present discussion has not been included. So we should make it clear what contents of science have to do with these examples, which the students have correct ideas about before learning. Because we will repeat, without notice, the same mistake that is stated in these results if we teach without knowing them.

In learning or understanding scientific concepts, then, it is not just the amount of knowledge that matters, though naturally greater knowledge tends to lead to greater understanding. The nature of the knowledge which one has and the pattern of associations between the old and new knowledge they will learn are important too. Concerning these matters, the statements once Whitehead made are vividly recalled (1967); above all the education which is not based on a vivid idea is not only needless but also harmful. According to Whitehead, the idea that is not vivid means that it is not used, not tested, not placed in new relations and it is no more than something that is crammed into one's head. This statements shows the essence of Whitehead's thought of education.

These statements nicely fit the results of this study. The author thinks that one of the most necessary things in Japan's education is this kinds of thinking. This papers' results may be observed in every country. However, at the same time the Japanese school system has been criticized these days for several reasons: too much work based on rote memory, but on too little creative or individualistic thinking and so on (Seibert, et al., 1991). On the other hand, it is said that educational standards of Japan are the highest in the world, and the Japanese teenagers are about two years ahead of their contemporaries in Europe and the United States (Lynn, 1988).

To find out which is appropriate, we must wait for the results of more researches, but the author can point out from the results of this study that the Japanese students, especially university students, scholastic competence in science is not satisfactory in terms of quality (for example, Hori, 1989; Hori and Akaike, 1992). This scholastic competence mainly means the patterns of association of knowledge in long-term memory.

4.3 An experiment that gives unexpected results does not always produce conceptual conflicts

In this study, the author has tried to demonstrate an experiment which is contained in Question 1. The experiment contains unexpected results to many students, since perhaps they have never seen such an experiment. Up until now, it has been said that many students produce cognitive conflicts when they watch the experiment that gives unexpected results. For example Gagné (1985) states the conceptual conflicts: "In science, demonstrating an experiment that gives unexpected results produces conceptual conflict and motivates students to understand why the results were different from those expected." But many students do not have conceptual conflicts even though they watch the unexpected experiment. So, as Nussbaum (1985) makes observations on these subjects, it is absolutely necessary that if we want to enable students to benefit from conceptual conflict we must help them expose and articulate openly their prior knowledge and concept. Because students do not see the differences between their own ways of thinking about a phenomenon and scientific ways of thinking about it.

Many researchers have already proposed and attempted teaching strategies to engage students in conceptual conflict (for example, Jones and Idol, 1990). In addition to that, the author wants to propose the following two points.

First, it is necessary to make sure what concept or phenomenon corresponds to the cognitive conflict for each student. The same concept or phenomenon is not always recognized as a cognitive conflict by each student just because they have not seen it as a conflict and have their own cognitive conflicts.

Secondly, it is necessary to clarify the method that produces students' cognitive conflict. That is to say, the method is such that the teacher makes students write about their change between before and after the instruction and compare the documents of the contents which are written by the same students. And then, the teacher makes students write what they think, how and why their thinking is different from the beginning, and so on (Hori and Ichikawa, 1993). It takes a long time for every student to take heed of the prior knowledge and concept that they already have. So, it is important to place the method, namely self-evaluation concerning cognitive strategies, in the learning and teaching whenever it is necessary.

A CONCLUDING STATEMENT

In this paper, through only one example, the author has tried to mainly clarify that to learn a new scientific concept does not always promote a better understanding of the concept and how learner's knowledge is interconnected in the understanding of the scientific concept. As has been previously stated, we have still many problems to solve concerning the teaching and learning. Especially, nothing is known yet about why some people acquire more useful sets of strategies than others (White, 1988). So, in the first place, we should begin with grasping the actual situation of students' cognitive strategies. Because the author thinks that we can not avoid touching on the cognitive strategies when we examine the problems of how learners' knowledge is interconnected. We will only then clarify how to develop the patterns of associations of knowledge in the understanding of the scientific concept and to nurture the cognitive strategies.

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