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A STUDY ON THE TEACHING STRATEGY OF FORCE AND MOTION:

A method of exchanging the students' misconceptions
with scientific knowledge

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INTRODUCTION

In the past several years there has been a significant increase in research dealing with students' misconceptions of science prior to formal instruction (Gilbert & Watts, 1983; McCloskey, Washburn, & Felch, 1983; Fisher, 1985). These previous works show that even after formal instruction misconception will remain and may play a crucial interfering role in the learning of any field of science. What kind of teaching methods should science teacher employ in the classroom?

Before considering this question, the word 'conceptual change' should be defined. According to the study of Posner et al. (1980), there are two processes involved in the acquisition of scientific knowledge: First, the process of assimilation in which students use existing concepts to deal with new phenomena, and second, the process of accommodation in which students' central ideological commitment requires modification. For example, the latter process could be utilized when attempting to exchange students' adherence to Aristotelian mechanics with an acceptance of Newtonian mechanics. In this paper, we specifically refer to this process of accommodation as the process of conceptual change.

Previous works have proposed a number of strategies for conceptual change. Nussbaum and Novick (1982) developed method for promoting cognitive accommodation in the classroom by 'conceptual conflict'. They refer to the importance of an individual's metaphysical beliefs and propose a teaching method. The teaching method consists of two events: exposing event and discrepant event. The exposing event assisted students to expose or to be aware of their misconception using a relevant subject, and discrepant event assisted students to exchange their misconception that students exposed in the first event with scientific knowledge using cognitive conflict. In particular, they emphasized the discrepant event of importance and expected teachers to propose problems that make students undergo cognitive conflict. Osborne et al. (1985) developed a model of conceptual change in which students learn scientific concepts in a process of four phases: preliminary, focus, challenge and application, based on the generative learning model (Osborne & Wittrock, 1983). In the first phase, preliminary, students attempt to discover their misconceptions. During the second phase, focus, students are assisted in considering the problem from many view points and present their idea to their classmates. In the third phase, challenge, students compare and analyze their misconceptions with each other. In the last phase, application, students apply their new concept to solve other problems that teacher present.

In summary, the most general way to exchange misconceptions with scientific knowledge is through 'awareness', 'cognitive conflict', and 'application'. In this general method, however, there are problems that are not yet scientifically confirmed as follows:

1. At the step of 'awareness':

Will this step make students' misconception to be high robust for change or not? The awareness or exposing students' misconception is a step in which they are assisted to expose their misconception, and this step probably has students grasp their misconceptions with constructing knowledge. Consequently, this step possibly makes students to be persistent in their misconceptions. Thus it is not obvious whether the step 'awareness' is useful for conceptual change or not.

2. At the step of 'cognitive conflict':

Will a student always be a falsificationismist? Although students are expected to undergo cognitive conflict, students do not always do so with problems or subjects that their teacher has proposed as the relevant for conceptual change.

Nevertheless, there are few practical previous works for classroom conceptual change, because of the absence of sufficient positive data. Although there are studies that pointed out the cognitive conflict or falsification of importance (Hashweh, 1986), few studies have emphasized the step, 'awareness', of importance. For example, though Nussbaum and Novick (1982) said that the Awareness as the exposing event is important, they argued that the 'discrepant event' is a more important step in an instructional strategy for facilitating accommodation in learning the particle model. Further it seems that other previous works do not look upon the step 'awareness' as the difficult step for students to expose their misconception. Thus we need to make sure whether the step, 'awareness' is a difficult step or not, moreover whether exposing misconceptions is useful for conceptual change or not.

In this paper, we first investigated whether students can be aware of their misconceptions or not. From this investigation, we found it difficult for students to become aware of their own ideas as misconception in mechanics. Second, we propose a new and practical teaching strategy, called a method of elaboration, based on a hypothesis that there is a strong need for some devised event being able to promote exposure of misconception in the students in learning the Newtonian's mechanics. Last, we conducted a comparative experiment to make sure whether the new method is useful or not by comparing the pre-test and post-test results of two participating classes, using the test of significance as a statistical method.

RESEARCH ON WHETHER STUDENTS HAVE THEIR MISCONCEPTION CONSCIOUSLY OR NOT

We probed students' knowledge about motion in nonquantitative problems concerning the behavior of a moving object. The purpose of the research in this section is to investigate whether students are aware that their knowledge takes a form of a system of misconception as Aristotelian mechanics or not. The problem, in which a person throws an object straight up into air, is cited from Gilbert et al.(Gilbert, Watts, & Osborne, 1985), as in Fig.1. This problem consists of three sub-problems. Gilbert et al. investigated to what extents students have the idea of Aristotelian mechanics. Osborne(1985) considered that this problem can be used to distinguish between students who have a notion about Aristotelian mechanics and students who have a notion about Newtonian mechanics. Moreover Osborne advocated that a number of children have a notion of Aristotelian mechanics and the notion is difficult to change. Nevertheless, the assumptions implicit in their studies are that students have their misconception consciously and explicitly and that this problem can elicit their cognitive structure from students in mechanics. On the basis of this assumption, the results of this research in this section would show that a number of students have a notion of Aristotelian mechanics. Thus most students would choose bca.

In this research, subjects were 121 seventh graders, who have not yet studied about force and motion, 107 eighth graders, who have not yet studied about force and motion, and 116 ninth graders, who have completed mechanics, at Enzan Junior High School in Japan.

Research results

A summary of our results obtained using this problem in Japan is given in Table 1, while the results of Gilbert et al. in Table 2.

Table 1: Summary of results in this research

Response pattern	Response pattern for students' age group(%)		
	12-13 (n=121)	13-14 (n=107)	14-15 (n=116)
b-c-a	32.2	36.4	11.2
a-a-a	9.1	19.6	54.3
(other)	58.7	44.0	34.5

Table 2: Summary of results in Gilbert et al.'s research

Response pattern	Response pattern for students' age group(%)		
	12-13 (n=254)	13-14 (n=195)	14-15 (n=174)
b-c-a	46	53	66
(other)	54	47	34

In Gilbert et al.'s research, the results showed that almost half students have misconceptions as Aristotelian theory, and other half of the students do not have consistent knowledge for the three sub-problems. In the mean time, in our research, although the combined results showed that approximately one third of seventh graders and eighth graders have misconceptions, two third students don't have misconception as a theory of Aristotelian mechanics. From the results of our research, we didn't find every student had a misconception as an Aristotelian mechanics theory. What ideas do the two thirds of the students have about force and motion? Does this result show us that they don't have any misconception?

Hypothesis

Since students are not aware of their misconceptions, most students' knowledge that they bring in the classroom prior to instruction cannot be modified. Further their knowledge does not have a system as Aristotelian theory. However their knowledge consists of many sub-concepts. These sub-concepts do not form a network, but exist individually. This means that students have some knowledge about force and motion from their life. If they form a semantic meaning network with these sub-concepts, the network will take a form of Aristotelian mechanics theory. In other words, these sub-concepts will be components of misconception. As we referred to above, however, students do not have Aristotelian mechanics. Instead, they have sub-concepts, the components of Aristotelian mechanics. In this case most of students don't realize their knowledge consciously, and their knowledge can't be accessed from other systems even though the knowledge is of their own, because their sub-concepts take the form of procedural knowledge (Hashweh 1986). Thus two thirds of the students did not show consistent ideas. In this paper, according to the study of Karmiloff-Smith(1991), the problem should be viewed from a new angle as follows:

1. Students' misconception has no system as a theory, and consists of procedural knowledge individually. Misconception doesn't take a form accessible from other systems. Thus student cannot find the meaning of misconception even though those are of his/her own.

2. What we proposed is not that students are expected to expose their sub-concepts, but that students should be assisted to establish a theory of their own explicitly. As a result, pupil can get access to cognitive unconsciousness, that is misconception, and transform the misconception into an adaptive form.

In summary, I proposed the following guidelines for designing and sequencing of learning activities in mechanics where conceptual changes are expected. This is called the *method of elaboration* .

PHASE 1. Transform students' misconceptions as unconscious knowledge into conscious one:

a) Prediction of motion: Encourage student to solve the 3 problems (Fig.2) in turns and to predict with what kind of motion the body will move.

b) Reason 1: Assist student to explain the reason they predict in a), a prediction of motion, for each problem verbally and pictorially. In particular, when they explain the reason pictorially, I assist them to use 'an arrow of force'.

c) Experiment: Students test their predictions with experiments, and confirm whether their ideas for the subjects are correct or not.

d) Reason 2: Encourage students explain their idea using the arrow of force again. Through step a) to d), students transform their unconscious concepts into conscious misconceptions pictorially.

PHASE 2. Support modification in which students debate of their different ideas and create a new idea. Using the 4 steps proposed above, students describe their ideas explicitly, and their misconceptions as unconscious knowledge is transformed into conscious knowledge. At this time, since students have just construct a system of their own from the sub-concepts that they held before instruction, the most students' idea are not correct even though their ideas were modified as conscious knowledge.

Therefore I point out the ideas that explain the reasons for the three problems are incorrect logically, because most of their ideas are in conflict with the scientific knowledge before teaching ideas of mechanics. Then I encourage students to create another idea that is not conflict in logically. At last, I propose ideas of mechanics for students.

EXPERIMENT

From the hypothesis mentioned above, a comparative experiment was conducted. The subjects, of which we will explain the conditions and the nature in later, are divided into two groups. We designate one of the two an Experimental Group and the other a Control Group. The experimental group was taught by using the method of elaboration and the control group was taught by using ordinary method. I compared pre-test and post-test results of the two groups and evaluate these two methods. There are two points of argument for the experiment. One is to define a word that we call a method of elaboration, by comparing between the method of elaboration and the ordinary method, another is how to evaluate both the methods of elaboration and the ordinary method. Following, these two points are explained in detail. Also, the subject and a terms of the experiment are described.

1. Definition of the method of elaboration

We define the method of elaboration by comparing the two methods; the method of elaboration and the ordinary method. The features of the two teaching methods are shown in Table3.

A. Method of Elaboration

This is a method that teacher encourages students to build up a system that is consistent with the students' responses that they made on the three problems (Fig.2). From now we call the three physics problems the *three consecutive problems*. Most of the students' system that are made at this point is not correct from a scientific view point. Hence the teacher should point out the inconsistency of each student's system moving around the classroom and encourage students to create another idea that will be consistent with the three problems. This method has already proposed former section in detail.

B. Ordinary Method

In this method, the teacher asks students to solve one problem through discussion, experiment, and lastly the teacher gives students a correct answer. In general, the teacher does this procedure in turn for each problem one by one.

There are many methods on how to teach science. Since most teachers would regard this method as useful in Japan, I selected this method as ordinary.

In both methods, I taught mechanics using the three consecutive problems (Fig.2).

Table 3: The features of the method of elaboration and the ordinary method

method	procedure
Method of elaboration (experimental group)	problem1 -prediction problem2 -prediction problem3 -prediction ... problemN-prediction — Reason1-Experiment-Reason2 (discussion) (discussion)
Ordinary method (control group)	problem1 -prediction-discussion-experiment-confirmation problem2 -prediction-discussion-experiment-confirmation problem3- prediction-discussion-experiment-confirmation ... problemN-prediction-discussion-experiment-confirmation

The results of instruction in experimental groups are remarkable in what they reveal about students' knowledge about force and motion. I have classified students' responses on the three problems into four different types. An example of each response type is shown Fig.3, along with the number of students producing each type of response.

2. Evaluation

We analyzed the two teaching method from the two points of view; transfers of concept and transit conceptual levels between the pre-test and the post-test.

A. Problems for Transfer of Concept

A transfer is to recall knowledge that you have studied and to apply the knowledge in another context (Gagné, 1975), thus the evaluation of these two methods is to compare the post-test results of the two groups. We used three problems, what I call a free fall problem, straight up and down problem, and curtain rail problem, as they are shown in Fig.4.1, Fig.4.2, Fig.4.3 respectively. Although students had not directly studied these three problems in the class before the post-test , they could solve the three problems if they succeed in understanding Newton's first and second law through instruction by using the three consecutive problems (as shown Fig.2).

B. Transit Problem

In this case we used a problem called the airplane problem(Fig.5). We first presented students this problem as a pre-test in which students predict which way a bomb, that is dropped from flying airplane, will go. Then students watched a video tape, in which the behavior of the bomb after being released from an airplane had been recorded, to correct their answer, and they were encouraged to write what assumptions they made to arrive at their answer. At this time they were not taught why the bombs behave like that. After being taught mechanics by using a method of elaboration and ordinary method, students were assisted again to explain the reason why bomb behaves like that. During instruction, I did not refer to this problem.

Although nobody was able to explain a correct reason for the behavior of the bomb on the pre-test, students would get a correct explanation at post-test if they understand Newton's low by instruction.

Therefore I employed a method that would compare the transit rate between pre-test and post-test. Furthermore I have classified students' responses on this problem into four different types: scientific explanation, responses explained by analogy, responses explained by misconception, and others. An example of each response type is shown in Table 8.

3. Subject

One hundred fifty-five, ninth grade students at the Enzan Junior High School served as subjects.

Experimental group: 77 (male students; 40, female students; 37)

Control group: 76 (male students; 38, female students; 38)

A comparative experiment was conducted. Thus the scholastic ability of both groups should be at the same level before instruction. In other words, if there is a difference between the two groups' ability, there is no meaning to compare the results of the post-test . In order to test the ability of the two groups to see whether there is a difference between the two groups or not, we used an examination in the academic subject for this paper. After the test we performed an analysis of variance to test at the 0.10 level of significance whether there is a difference between experimental group and control group in their scholastic level.

As a result, since $F_{1,145}=0.19$, $P>.10$ no significance, we can accept the 0.10 level the hypothesis that there are equal means. It follows, before instruction there is no difference of scholastic level between the two groups.

4. A terms of experiment

from May 15 to June 7 in 1992

1. Pre-test: 1 unit
2. Pre-instruction: 2 units
3. Experiment: 3 or 4 units
4. Post-test: 1 units

1 unit = 50 minutes

At 1. Pre-test, 2. Pre-instruction, and 4. Post-test, both groups were taught using same way and same content. Although I performed two teaching methods for the two groups respectively, students studied mechanics through the same three consecutive problems. It means that only the teaching methods of two groups were different and that other conditions were all same. Further at pre-instruction, I taught students how to draw an arrow of force as review lesson and taught what is friction to both groups.

RESULTS

I have collected two sets of data for the evaluation of teaching methods from this comparative experiment. One was evaluated using the Problems for Transfer of Concepts and the other used Transit Problems. I use four problems in this experiment and three of the four are Transfer of Concepts and one of the four is Transit Problems. Although there were seventy-seven and seventy-six students in the experimental group and the control group respectively, they will be changed because of absences.

1) Evaluation using the Problems for Transfer of Concepts

We analyzed three problems, these were the free fall problem, straight up and down problem, and curtain rail problem shown in Fig.4.1, Fig.4.2, and Fig.4.3. Each problem consisted of a diagram, with instruction that explained the diagram and asked the students to make a qualitative prediction of an object.

1. Free fall problem

This problem consisted of three sub-problems (Fig.4.1). Students were asked to fill out questionnaires about the behavior of an object that would follow after it emerged from the top ignoring air resistance, and to draw the arrow of force to explain the reason for the behavior that students choose. The most important concept in studying mechanics as kinetics is to understand the relation between force and motion. The correct answers to these sub-problems are that constant gravity caused the ball to be accelerated. Table 4 presents the total numbers of the students who pointed out the correct answers for the first two sub-problems: the velocity of the object's motion is increasing and the arrow of force whose lengths are constant.

Table 4: The correct response for first and second sub-problems of Free fall problem

	experimental	control
correct	22(32.8%)	11(14.5%)
incorrect	45	65
(absent)	(10)	(0)

An exact probability was performed with two groups of the number of students who choose correct answer for the first and second sub-problems. The difference was significant ($p=.016<.05$) . Further students were asked to explain the reason for the behavior of the object and the constant length of force arrow. Then we analyzed students' explanations of the third sub-problems. In particular, we analyzed the explanations of the students who chose and drew correct answer on the first and second sub-problems, and these explanations were classified into three different types (Table 5).

Table 5: Explanation of Free Fall of one who gives correct answer about first and second sub-problem

students' explanation	experimental (n=22)	control (n=11)
1.accelerated by constant gravity (correct answer)	15	2
2.accelerated by gravity,but the force is not constant	4	4
3.(other or no answer)	3	5
total	22	11

Although the number of students who chose and drew correct answer on the first and second sub-problems and who wrote correct answer for the third sub-problem was two in the control group, the number of students who were taught using the method of elaboration was fifteen in experimental group.

2. Straight up and down problem

This problem also consists of three sub-problems (Fig.4.2). On the first sub-problem, the correct answer is that when the ball is going straight up, the velocity of the object will be decreasing, and vice versa when the ball is going straight down the velocity of the ball will be increasing.

On the second sub-problem, though the velocity of the object will be changed gradually, the object moves under the influence of constant force (in other words gravity). The number of students who got a correct answer on both sub-problems is shown in Table 6.

Table 6: The correct response for the first and second sub-problems of Straight up and down problem

	experimental	control
correct	13(19.4%)	3(4.0%)
incorrect	54	73
(absent)	(10)	(0)

An exact probability was performed with two groups, experimental group and control group. The difference was significant ($p=.0068<.05$) .

On the third sub-problem, no one was able to explain the correct relations between gravity and the straight up and down motion.

3. Curtain Rail problem

In this problem, there are four sub-problems (Fig.4.3). Students are asked about the motion of the object in the first, second and third problem. The number of students who gave the correct answers for the three sub-problems is shown Table 7.

Table 7:The correct response for first,second and third sub-problems of Curtain rail problem

	experimental	control
correct	16(23.9%)	4(5.3%)
incorrect	51	72
(absent)	(10)	(0)

An exact probability was performed with two groups, the experimental group and the control group. The difference was significant ($p=.0026<.05$) .

In addition, the correct answer for the forth sub-problem is that the ball X will reach b, when the ball Y reaches ground. Because the total velocity of the ball Y may be decomposed into dependent horizontal and vertical components, and according to the principle of inertia, the both balls' horizontal velocities will remain constant. Thus when the ball Y reaches ground, ball X reaches b. For this last sub-problem, eleven of sixteen students described a correct answer in experimental group, whereas three of four students indicate correct answer in control group.

2) Evaluation using the Transit Problems

We analyzed one of the four problems as the Transit Problem named a airplane problem, shown in Fig.5. In this case we introduced a method to evaluate and compare the usefulness of the two teaching method as follows:

1. Pre-test (1): Subjects are asked to predict about motion of the object.
2. Pre-test(2): The views are confirmed by the facts using video tape or experiment. Further students are encouraged to explain their idea, the reason for the motion that they observed.
3. Instruction: Experimental group's students are taught mechanics using the method of elaboration, whereas the control group's students are taught mechanics using the ordinary method. During instruction, I did not refer to this problem directly.
4. Post-test: Students are asked the reason for the object's motion after formal instruction again.

I made a comparison between experimental and control group on the transit their idea from pre-test (2) to post-test.

Results of the airplane problem as the Transit Problem

This problem, in which students were asked the motion of a bomb that was dropped from the continuous flying airplane (from now, we call this problem airplane problem), consists of two sub-problems. The first sub-problem asks students which course the bomb flies after being released it from the airplane. The second sub-problem asks students to explain the reason for the bomb's motion of the students' choice on the first sub-problem. Since students watched the video tape on the object's motion after pre-test(1), most students had a correct answer for the first problem. Thus the evaluation of the two teaching methods is to make comparison between explanation of pre-test(2) about the reason for the motion and explanation of post-test. During instruction, I did not refer to this problem at all. Nevertheless, if students understand the relation between force and motion through the instruction using the three consecutive problems and they are able to apply their understandings into this problem, at post-test the number of students who explain correct answer for the reason of the bomb's motion should be larger than that at pre-test. We compared the two teaching method using this problem.

The explanation of the second sub-problem took a variety of forms. Therefore I have classified their responses on this sub-problem into four different types as shown in Table 8.

Table 8: Classified table about the explanation of the airplane problem

A group	Scientific explanation: This is a correct answer about the motion of the large metal.
B group	Responses explained by analogy: Students explain the motion by the relevant analogy. However they don't realize the relation between force and motion.
C group	Responses explained by misconception: Students explain the motion by the idea that an object set in motion acquire an internal force, and this internal force keeps the object in motion.
D group	(other): Students just described the phenomena that they observed without any explanation for the reason or no answer etc..

I made a comparison between the experimental group and the control group on the transit from the number of each response for the pre-test(2) into the post-test by this classified table. The results are shown in Table 9 and 10. Five of the seventy-seven students and three of the seventy-six students in the experimental and the control group respectively were absent when they were examined.

Table 9:Transit from pre-test(2) into post-test in experimental group

	pre-test(2)	post-test
A. Scientific	0	32(44.4%)
B. Analogy	4	0
C. Misconception	21	16
D. (other)	47	24

Table 10:Transit from pre-test(2) into post-test in control group

	pre-test(2)	post-test
A. Scientific	0	5(6.8%)
B. Analogy	3	3
C. Misconception	18	14
D. (other)	52	51

Although students' responses about this problem on the pre-test(2) were approximately same, after instruction those students who got a correct answer on the post-test were 32 (44.8%) in the experimental group while 5 (6.8%) in the control group.

STUDENTS' RESPONSES IN THE METHOD OF ELABORATION OF THE EXPERIMENTAL GROUP FOR THE THREE CONSECUTIVE PROBLEMS

The method of elaboration is proposed as a teaching method, whose guideline for sequencing is in a process of two phases as aforementioned. For this experiment, I use the three consecutive problems (Fig.2). Phase 1 is 'Transform students' misconceptions' and Phase 2 is 'Support modification'. In particular, we will show the results of the first phase that consists of four stages: A prediction of motion, Reason 1, Experiment and Reason 2. In this section, we first present the students' responses of each stages in experimental group. Then we compare the responses that students draw at the last stage called Reason 2 with misconception that was identified by a number of previous works, specifically the work of Champagne et al. (1980), because the method of elaboration is expected to have students their misconception constructed. In addition through these four processes, students are expected to be able to transform their unconscious knowledge of which they have not recognize, and which they cannot explain verbally and pictorially into conscious knowledge that is constructed by explaining and drawing.

1. Students' responses for the four stages

At the first stage , 'A prediction of motion', a number of responses that students made are presented and these responses are classified into ten types for the three consecutive problems. At the second stage, 'Reason 1', students are encouraged to explain the reason for the prediction that they made in the first stage, by both drawing the arrow of force pictorially and describing verbally. For each response that is classified in the first stage, students present a number of different reasons. At the third stage, 'Experiment', teacher conducts demonstrational experiment for the problem 1 and 2 of the three consecutive problems. As for problem 3, students made experiments by themselves and teacher also demonstrated. Doing these, students had made certain of the fact of the object's motion in the three consecutive problems. At the last stage that is 'Reason 2', they are encouraged to explain the reason for the fact that they observed in the third stage by drawing the arrow of force again. Since they know the fact about the object's motion for these problems precisely at this last stage, students have their idea sophisticated or elaborated more than the ideas at the second stage when they drew the arrow of force as the reason for the object's motion. We have classified their drawing into four different types as shown in Fig.3. These are students' elaborated ideas.

2. The comparison between students' responses for the three consecutive problems in Reason 2 and misconceptions.

Most students draw a force that is in proportion to the velocity of the moving object as pattern 1, 2 and 3 in Fig.3. In the meantime previous studies about force and motion have been reported, and Champagne et al. (1980) say:

(1) a force, when applied to an object, will produce motion;

(2) under the influence of a constant force, object move with constant velocity;

(3) the magnitude of the velocity is proportional to the magnitude of the force; any acceleration is due to increasing force;

(4) in the absence of force, objects are either at rest or, if they are moving (because the stored up momentum while previous forces were acting), they are slowing down (and consuming their stored momentum).

These misconceptions are congruent with the students' drawings of the arrow in the classroom as shown in Fig.3. This means that students construct their systems as the theory similar to the aspects of Aristotelian mechanics and that they have their idea, which they were unable to grasp consciously before instruction, to be explicit and conscious. Hence students are able to transform their cognitive unconscious knowledge into consciousness, because they can access their ideas.

In the second phase, that is 'Support modification', we pointed out the inconsistency about their drawings and students are encouraged to create other ideas. However most students were not able to create a correct answer. Therefore I proposed a correct answer and made students modify their misconceptions with scientific knowledge. Aforementioned results show this new method to be useful.

DISCUSSION

On the basis of our findings from the comparative experiment in which the results of pre-test and post-test were compared, we shall discuss in this section that the new method, called the method elaboration, proved to be useful in teaching mechanics and that on what the reason for the usefulness of the new method depended.

1. Usefulness of the method of elaboration

Having collected two sets of data from the experiment, we shall discuss that the new method is useful. One set of data was collected by using the problems for transfer of concepts that consist of three problems and the other set of data used the transit problem that consists of one problem as we have referred previously.

A. Evaluation of teaching methods using the problems for transfer of concepts

The results of the problems for transfer of concepts, which consists of three problems called free fall, straight up and down, and curtain rails, show that there were significant differences between the experimental group and the control group. We taught mechanics using the method of elaboration in the experimental group, while using the ordinary method in the control group. Since only the teaching method was different, the teaching method caused the results of these problems to differentiate. Thus, according to these results, the method of elaboration is a more useful teaching method in mechanics than the ordinary method.

B. Evaluation of teaching methods using the transit problem

The problem, called the airplane problem, measures the results of transit from the explanation of pre-test(2) into those of post-test. The results of the inquiry show that students' responses in experimental group are different from the responses in control group at the post-test, while at the pre-test(2), prior to the instruction, students' explanations about the reason for the motion of the object, a large metal ball were approximately same in both experimental group and control group. Students who answered correctly in experimental group outnumber those of in control group.

In summary, the result of this research shows that the method of elaboration is far more useful than the ordinary method in teaching mechanics as a teaching method of conceptual change.

2. Reason for the usefulness of the method of elaboration

In this section, we consider the reason for the usefulness from the three points of view: first, the meaning of the method of elaboration as a way that makes students to think a number of problems to be consistent with each other in students' mind; second, discussion from the aspects of metacognition; third, the method of elaboration will satisfy a part of the conditions of conceptual change.

A. The meaning of the method of elaboration

In this method, students are encouraged to think the three consecutive problems to be consistent with each other. When teachers teach mechanics by using ordinary method, which present students with problem one by one, only one concept in their mind will be made active. Thus, when a teacher modifies their students' ideas into correct answers one by one in the ordinary method, teachers have thought that students will change their all framework after instruction using the ordinary method.

However, since one of the characteristics of students' process of thinking in science is content-dependent (Anderson, 1980), it is very difficult for students to change their framework being taught using method in which students are presented subjects one by one. Further, Ross(1990) emphasized that in order for students to achieve meaningful conceptual understanding, to form links between a number of concepts is more important than to learn the meaning for each concept. Moreover, students cannot make networks or links without instruction.

Ordinary method may play a role that modifies students' incorrect answer of the one subject that is presented in the classroom. Even though students change their idea about the subject, it is difficult for them to realize their misconceptions as a cluster called conceptual ecology (Posner,Strike, & Hewson, 1982) in which their incorrect concept is embedded. Further it is also difficult for teacher to get students to know that the modifications of the answer for the subject imply their network reconstructed.

In the meantime, being taught using the method of elaboration, students are encouraged to make system of their own from not only the three consecutive problems, but also the phenomena that students experienced from real-world knowledge. In fact, when students tried to make a system by discussing it in the classroom, they referred not only to the three problems, but also another knowledge:

Student 1: Where will I land, when I jump inside a moving train?

Student 2: If I throw a stone from the window of a moving train, which way will the stone go?

Student 3: In space, if you are pushed by somebody and you have no machine, then can you return back again?

These remarks show that students,who were taught mechanics through the method of elaboration, attempted to make network or system by using the three problems and other concepts of real-world knowledge, whereas I presented the only three consecutive problems. This means they made broader networks of knowledge as a system that they never made through the instruction of the ordinary method.

In summary, being taught mechanics using this new method, students are encouraged to construct a system of conscious knowledge from the unconscious knowledge that they brought into the classroom. This method assists students to elaborate their system as a theory using both the three consecutive problems and students' real-world knowledge from their cognitive unconsciousness.

This first phase in which students construct their system explicitly, however, does not help students to accomplish conceptual change. Through the second phase, pointing out their inconsistencies in the elaborated knowledge that students construct in phase 1, students are encouraged to exchange their elaborated ideas into another idea for conceptual change.

Thus, through two phases: first phase of this new method has students construct a system as a cluster of knowledge; second, the teacher points out of inconsistencies of the system; the method of elaboration is useful to exchange misconceptions as the students' unconscious idea with scientific knowledge.

B. The method of elaboration as instruction of metacognitive knowledge

The arguments in which metacognition promote students' learning have been proposed. Paris(1991) described some features of metacognition:

> *Most researchers have now blended those twin approaches (that are studies of Flavall and of Brown) into a definition that emphasizes (a) knowledge about cognition states and processes and (b) control or executive aspects of metacognition. This familiar dichotonomy of the mind is consistent with information processing accounts of declarative and procedural knowledge and captures two essential features of metacognition --self-appraisal and self-management of cognition.*

Our new method strongly relates to the former, self-appraisal. Further, Paris et al. (1991) said:

> *Because self-appraisal answers questions about what you know, how you think, and when and why to apply knowledge or strategies... Many students have shown that students are not adopted at cognitive self-appraisal... because they rarely monitor their knowledge...*

In the meantime, our new method functioned as a method in which students are encouraged to construct their misconceptions, that students do not realize as conscious knowledge or a system. Furthermore, the questions about what you know and how you think, that are cited from Paris et al., correspond closely with the questions in science education whether students monitor their misconceptions or not and how to apply the scientific concepts instead of misconceptions. The method of elaboration encourages students to realize the knowledge that they store up and that is unconscious by constructing systems, and assist students to be aware of how to think. Thus the new method plays a role to promote students' self-appraisal, which is the first feature of metacognition.

As a result, we found the method of elaboration of great useful for conceptual change.

C. The method of elaboration will satisfy a part of the conditions of conceptual change

Posner et al. (1982) identified four conditions for conceptual change: (1) there must be *dissatisfaction* with existing conceptions; (2) a new conception must be *intelligible* ; (3) a new conception must appear initially *plausible* ; (4) a new concept should suggest the possibility of a *fruitful* research program;

The method of elaboration will satisfy the first condition of the four. It is impossible that the new method will satisfy all four conditions. However the students who discovered their misconceptions as conscious knowledge and who found their ideas incorrect became dissatisfied with their conception that they constructed as a system. Thus, that the method of elaboration satisfies the first condition is one of the important contributing factors to conceptual change in teaching mechanics.

CONCLUSION

These two points have been definitely shown by our control experiment on the teaching strategy of force and motion:

(1) The new teaching method, which is called the method of elaboration, makes students transform their misconceptions as unconscious knowledge that they brought in the classroom into conscious knowledge.

(2) The new method makes students construct a system as a theory from misconceptions by using a strategy where we introduced problems (in this paper we use the three consecutive problems) as parallel.

Further, we have proved that the two points described above contribute to the students' conceptual change in teaching mechanics.

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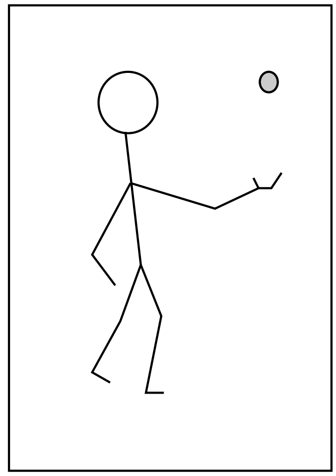
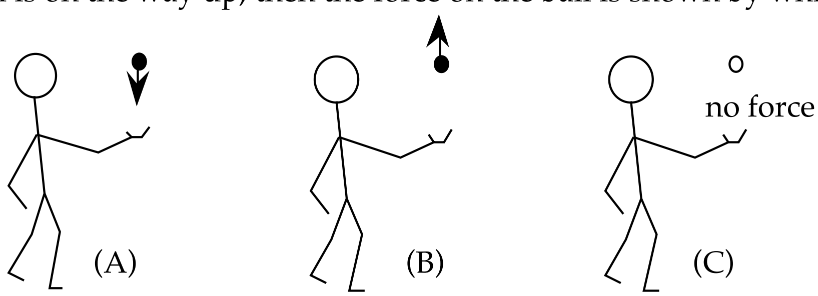
A person throws a tennis ball straight up into the air just a small way.

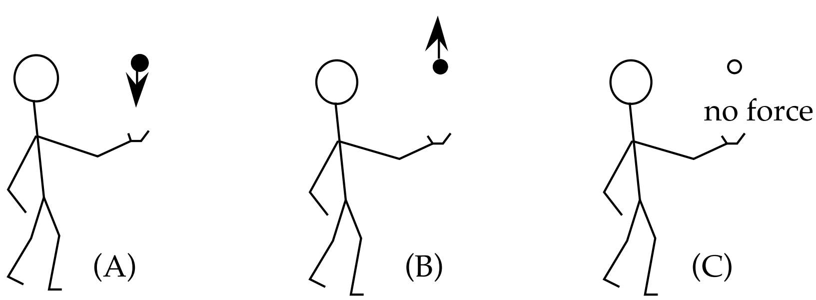
The questions are about the total force on the ball.



If the ball is on the way up, then the force on the ball is shown by which arrow?



If the ball is just at the top of its flight, then the force on the ball is shown by which arrow?



If the ball is on the way down,then the force on the ball is shown by which arrow?

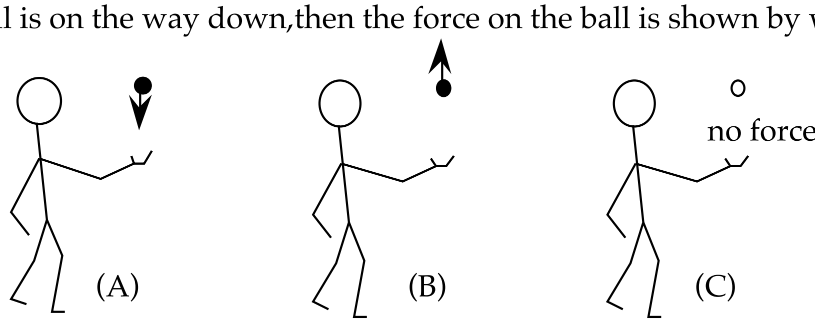


Fig.1: Research problems
(after Gilbert, Watts, & Osborne, 1985)

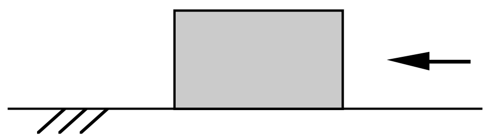
PROBLEM 1 An object is at a rest. There is a friction between the object and the surface of the table. Force is applied on the object and then the force is completely withdrawn. The arrow shows the direction in which the object is moving. After applying force, is the velocity of the object's motion:

a) quickly decreasing

b) slowly decreasing

c) continuous at the same speed

or d) increasing



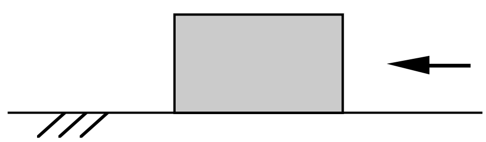
PROBLEM 2 In this subject, a frictionless object is at a rest. Force is applied on the object and then the force is completely withdrawn. The arrow shows the direction in which the object is moving. After applying force, is the velocity of the object's motion:

a) quickly decreasing

b) slowly decreasing

c) continuous at the same speed

or d) increasing



PROBLEM 3 A frictionless object is at a rest. The object is pulled so that the spring on it is always extended constantly. The arrow shows the direction in which the object is moving. Is the velocity of the object's motion:

a) slowly decreasing

b) continuous at the same speed

c) increasing

or d) other

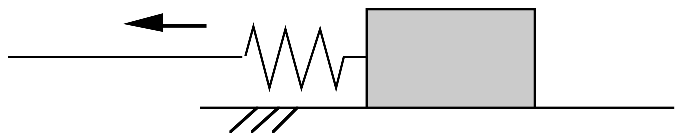


Fig 2: Three consecutive problems used in the classroom

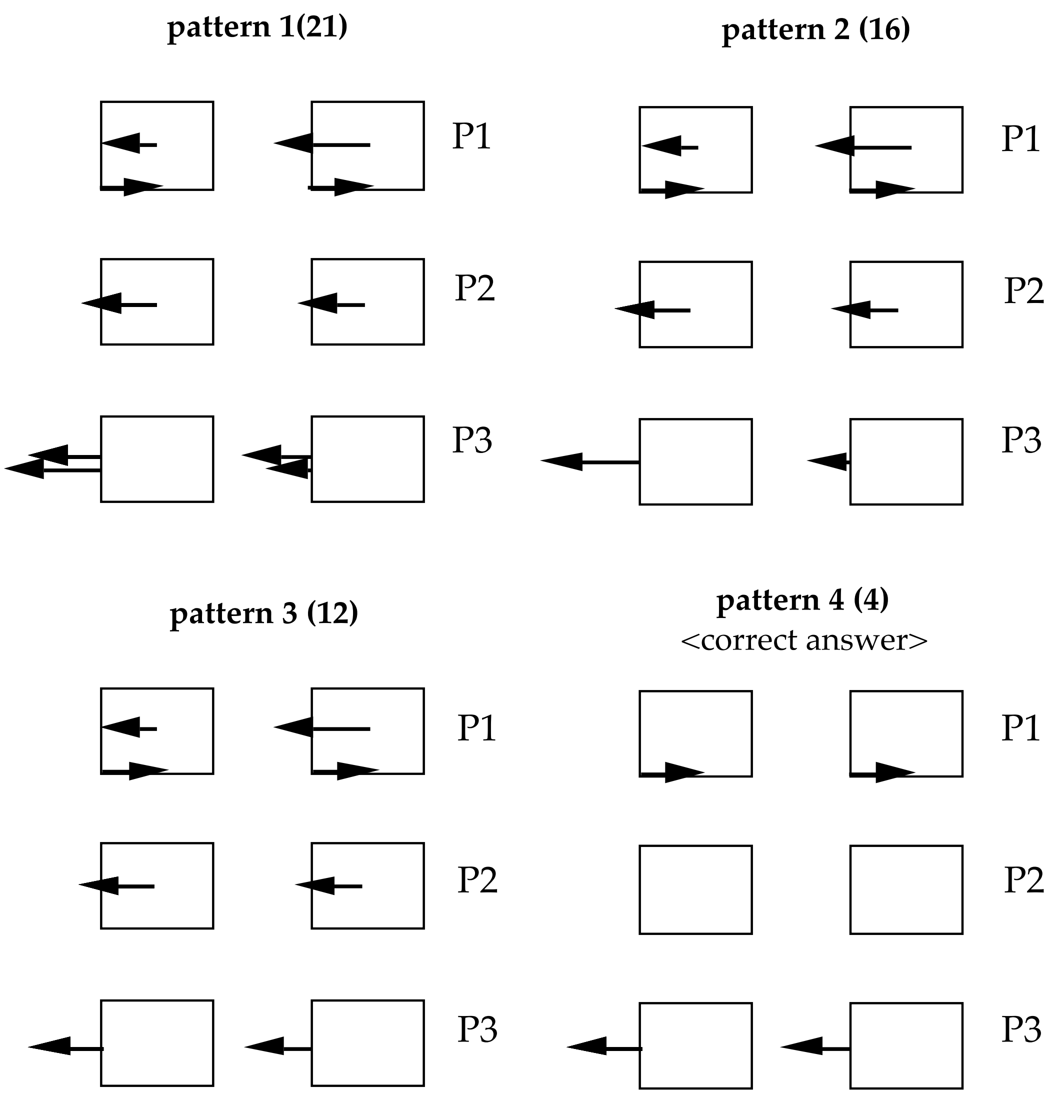


Fig.3: Students' responses on the Reason 2 (elaborated ideas)

Free fall problem

A ball falls freely from rest which is about 10 ft above the ground.

(1) The velocity of the ball will be:

(a) increasing

(b) continuous at the same speed

(c) decreasing

(2) The diagram shows the ball's path. Suppose someone releases the ball in position A. Draw the arrow of force on the balls from A to D.

(3) Explain the reason for the relation between the force and motion.

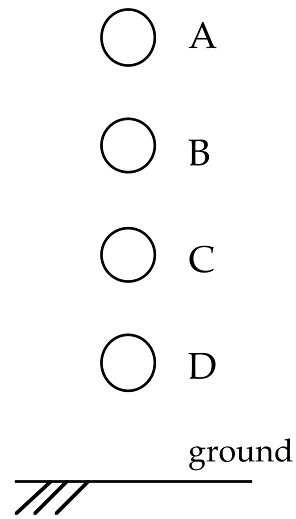


Fig 4.1: Free fall problem
(Problem for Transfer of Concept)

Straight up and down problem

A ball is thrown vertically upward and it returns to the starting point.

(1) If the ball is on the way up, the velocity of the ball will be:

(a) increasing

(b) continuous at the same speed

(c) decreasing

If the ball is on the way down, the velocity of the ball will be:

(a) increasing

(b) continuous at the same speed

(c) decreasing

(2) The diagram shows the trajectory of the ball. Draw the arrow of force on the ball that is for each condition, on the way up, the top of its flight and on the way down respectively.

(3) Explain the reason for the motion in which the ball is on the way up, using the relation between force and motion.

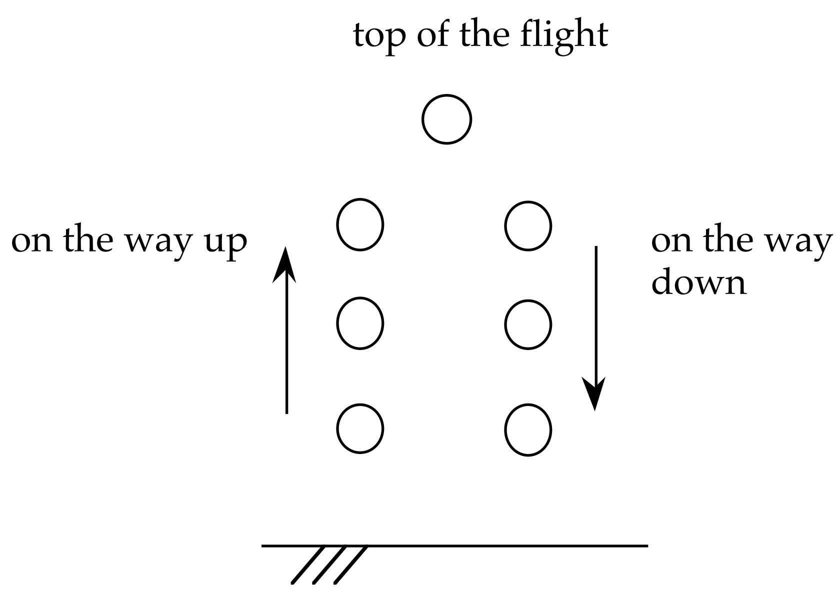
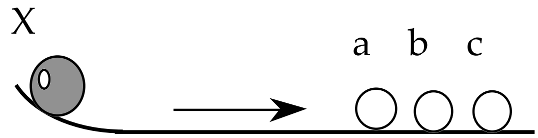


Fig.4.2: Straight up and down problem (Problem for Transfer of Concept)

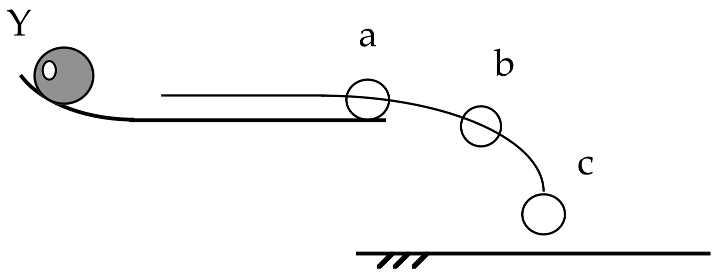
Curtain rail problem

(1) In the diagram, a metal ball is released from the top of the slope that is made of bent curtain rail . After released, the ball is moving on the rail. Then what kind of force is acting on

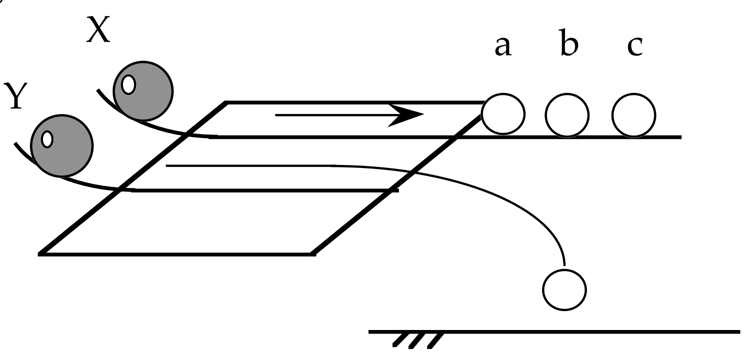
the ball? Draw the arrow of force on the ball at the positions a, b, and c. The slope is frictionless (in other words, perfectly smooth), and ignore air resistance.



(2) In the diagram, a metal ball is also released from the top of the slope. After sliding along the curtain rail, the ball is flying down to the ground. The drawn line is the path that the ball will follow after it goes over the edge of the curtain rail. Draw the arrow of force on the ball at the positions a, b, and c.



(3) The diagram shows an apparatus that has two curtain rails being set as parallel. One is longer than the other. The two balls are released from the top of the rail at the same moment. When the ball Y reaches ground, what is the position of ball X in the diagram? Choose the position from a, b, or c.



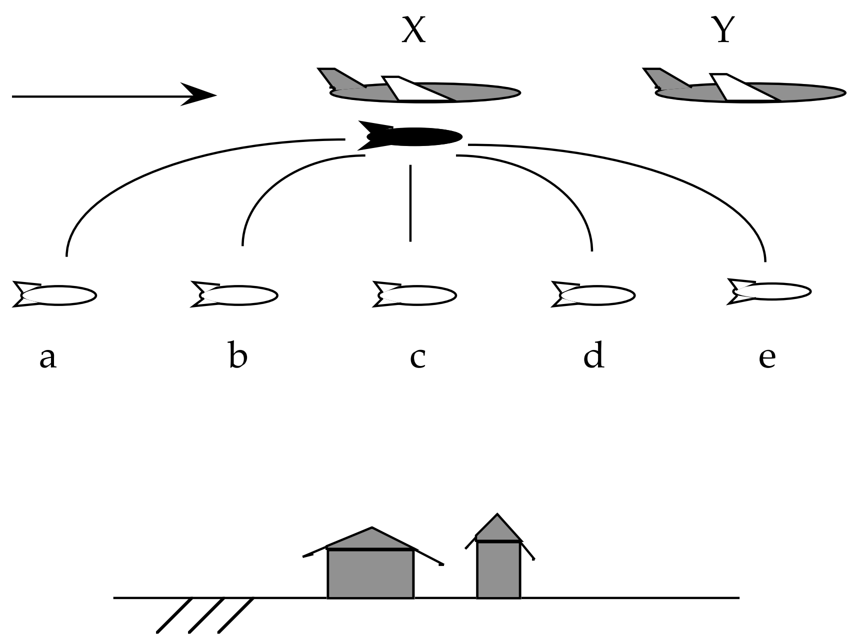
(4) Explain the reason for the prediction that you make for the third sub-problem.

Fig.4.3: Curtain rail Problem
(Problem for Transfer of Concept)

Airplane problem

In the diagram, an airplane is flying along at a constant speed. The plane is also flying at a constant altitude, so that its flight path is parallel to the ground. The arrow shows the direction in which the plane is flying.

(1) When the plane is in the position X shown in the diagram, a bomb is dropped from the plane. The plane continues flying at the same speed in the same direction and at the same altitude. After that, the plane reaches the position Y. Then, what kind of path way does the bomb draw? Choose the path from a to e. Ignore the wind or air resistance.



(2) Explain the reason for the choice why the metal flies so in the first sub-problem.

Fig.5: Airplane problem
(Transit Problem)