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Scaffolding for Self-overcoming of Impasse by Using Problem Simplification

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Abstract: As a support for learners who failed to solve a problem, teaching the way to solve the problem is a general method. However, in order to realize active learning, it is a desirable way to let learners overcome the impasse of the problem solving by themselves. Because it is usually difficult for the learners to do it by themselves, we have proposed "problem simplification" that is a way to find a simplified problem that is included in the original problem from the viewpoint of problem solving. If the simplified problem can be solved by the learner, the difference between the simplified one and the original one is the origin of the impasse. To make clear the origin of the impasse is feasible scaffolding for self-overcoming of impasse. In this paper, firstly we propose a framework to define simplification of problems in elementary mechanics in high school. Then, it is introduced a support system for self-overcoming of impasse of problem solving using the problem simplification targeting elementary mechanics. We also report a practical use of this system in classes of a technical high school.

Keywords: Problem Simplification, Self-overcoming, Impasse, elementary mechanics

1. Introduction

Problem exercise is an indispensable step in learning of physics, mathematics and so on. When a learner engages in the problem exercise, the learner usually has enough knowledge to solve the problems in the exercise. However, the learner often fails to solve a problem because it is difficult for the learner to use knowledge adequately to solve the problem. In such case, to explain how to solve the problem is a standard method in usual teaching. This method is effective to let the learner solve the problem. However, because the learner often accepts the way to solve the problem passively, it is not effective as learning. In order to use failure of problem solving as an opportunity of learning, it is desirable to let the learner to overcome the failure or impasse of the problem solving by him/herself (Polya, 1945; Perkinson, 1984). In this paper, targeting elementary physics, we propose "problem simplification" to support a learner to overcome his/her impasse in problem solving by him/herself.

Even if a learner cannot solve a problem in an exercise, the learner usually has almost enough knowledge to solve the problem. Then, a few elements including the problem often cause the difficulty for the learner to solve it. In such case, it is possible to expect that the learner can solve a problem generated by deleting the elements in the original problem by him/herself. If the simplified problem is solved, it is possible to specify the cause of the difficulty for the learner as the difference between the original problem and the simplified problem. When a learner to engage in a new and difficult problem, it has been confirmed that to make clear the difference between the difference between the new problem and the problems that have been already solved is a promising way (Sheiter and Gerjets, 2002; Sheiter and Gerjets, 2003). Therefore, in the case of impasse of problem-solving, we assumed that such simplified problems are useful to overcome the impasse in solving the original problem. If the learner can solve the original problem after solving the simplified problem, the learner was supported but didn't teach the way to solve the original problem. So, we call this process "self-overcoming of Impasse".

In order to use the simplified problem in problem exercise, however, it is necessary to generate the simplified problem from the original one. Therefore, in this research, we define "problem simplification". Simplified problems used in the process should be included in the original problem from the view point of problem solving. The definition of the simplification is carried out based on

Microworld Graph describing simplification-complication relations between physical situations (Horiguchi and Hirashima, 2005; Horiguchi and Hirashima, 2009).

We have already implemented a system that support a learner in impasse of problem solving by using problem simplification targeting physics of high school. Because the system is implemented on tablet PC, it is possible to use the system in a usual classroom. We have already conducted practical use of the system in physics class in a technical high school. 130 students in three classes were used the system in one class time (45 minutes). Almost of them could use the system smoothly and we found behavior of self-overcoming of impasse from more than half of them. Also to other students, we could find focused their weak points.

This paper describes description of each problem and relations between problems in Section 2. The problem simplification supporting for Self-overcoming of impasse is explained in Section 3. This paper also reports a practical use of this system in classes of a technical high school and its results in Section 4.

2. Derivative Problem

As shown in Figure 1, previous research has defined the elementary mechanics problem as “situation” and “solution” (Okawachi, Ueno and Hirashima, 2012). Problems defined based on the situation, and the situation has attributes, such as gravitational acceleration and mass, and operational relations which is the relationship among attributes. The solution is defined by connecting attributes given in a problem sentence by means of operational relations defined in the situation. We call it solution structure (Hirashima, Kashihara and Toyoda, 1995). This is a tree structure composed of input attributes which are leaf nodes, output attribute which is a root node, derived attributes which are the others nodes, formula nodes which connect their attributes, and edges. Input attributes is attributes explicitly given in a problem sentence (blue nodes in Figure 1), output attribute is attribute which learners should seek by connecting input attributes(red node in Figure 1), and derived attributes is attributes which learners acquired in the middle of solving the problem (green nodes in Figure 1). How to the read solution structure in Figure 1 is that firstly “Gy” (gravitation of block A in vertical direction) is derived from “m” (mass of the object) and “g” (acceleration of the gravity) which are input attributes, using formula node “gravitation of block A (vertical)”, then “N” (normal force) is derived from “Gy” using formula node “normal force”, then “f” (dynamic friction) is derived from input attribute “μ” and derived attribute “N” using formula node “dynamic friction”, and lastly output attribute “Fx” (resultant of block A in parallel on the surface) derived from derived attribute “f” and input attribute “Tx” using formula node “resultant of block A (parallel on the surface)”.

We call the problem which has relevance from a viewpoint of the situation or the solution, "derivative problem" (Okawachi, Ueno and Hirashima, 2012). Automatic generation function of the formalized derivative problems had already been developed in the previous research. In the following subsections, the two types of derivative problems are explained.

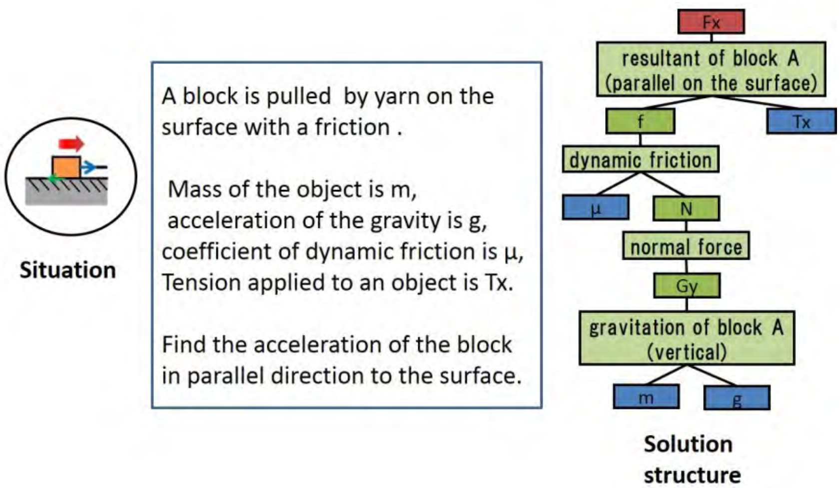

Figure 1. Problem and Solution Structure.

2.1 Specialized/Generalized Problem

A specialized problem is generated by specialized a certain attribute, such as an angle of inclination and friction coefficient, which the situation of a certain problem has. This problem has simpler situation than original problem has. The specialization is making a certain attribute into a specific value. The solution of the specialized problem does not change from the solution of the original problem. Therefore, this problem is included by the original problem from the viewpoint of problem solving, so if learners can solve the original problem, they can inevitably solve the specialized problem.

A generalized problem is generated by adding a certain attribute to the situation of a certain problem. This problem has more complex situation than original problem has. The generalization is the opposite of specialization. The generalized problem includes the original problem from the viewpoint of problem solving, so if learners cannot solve the original problem, they cannot inevitably solve the generalized problem.

We use a model called a micro world graph for transition of the situation. This graph is comprehensively described situations which are derived from a certain situation (Hirashima, et al, 1994; Horiguchi and Hirashima, 2009).

2.2 Partialized /Expanded Problem

A partialized problem has a part of solution structure of a certain problem as a solution of this problem. This problem is generated by making derived attribute input attribute, or derived attribute output attribute. Thus, extracting a part of solution is called the partialization. The partialized problem is included by the original problem from the viewpoint of problem solving, so if learners can solve the original problem, they can inevitably solve partialized problem.

An expanded problem is generated by making input attribute derived attribute, or output attribute derived attribute. The expansion is the opposite of partialization. The expanded problem includes the original problem from the viewpoint of problem solving, so if learners cannot solve the original problem, they cannot inevitably solve expanded problem.

3. Problem Simplification Strategy

3.1 A Summary of Problem Simplification Strategy

One of a purpose of the problem exercises is finding where learners reach an impasse in problem solving. For this purpose, when learners cannot solve a certain problem, they need to recognize the origin of the impasse. In order to have learners recognize it, let us use the following idea. Considering a problem structurally, the problem is made by complicating “a situation” or “a solution” of the simplest problem derivatively. Therefore, more complex problem includes simpler problem from the viewpoint of problem solving, and if learners can solve more complex problem, they inevitably can solve simpler problem. According to this idea, we can consider that problems are made hierarchically. We call this idea “Derivative Establishment Model of the Problem”.

Considering problems as things with such relationship, we can say that when a learner cannot solve a certain problem, he/she cannot solve the part in this problem, not the entire. Taking a difference between problem which a learner cannot solve and simpler problem which a learner can solve, this difference is the origin of the impasse in solving the problem which a learner cannot solve and the part which they should overcome. Based on this idea, if learners cannot solve a certain problem, the problem is simplified until they find a problem which they can solve. After they find the problem which they can solve, taking a difference between the original problem which they couldn’t solve and the simplified problem which they could solve, they can recognize the origin of the impasse in solving the original problem. We call this strategy “Problem Simplification Strategy”. Although it is difficult for learners to consider combining the simplified problem and the difference as learners return to the original problem from the simplified problem, they can easily recognize their origin of the impasse, comparing to usual exercise. We assume that learners may overcome their impasse of the original problem which they couldn't solve by themselves without some teaching activities, by tackling the problem with their being conscious of their origin of the impasse and recognizing the relationship of the problems, because learners usually have enough knowledge to solve the problems in the exercise. On the other hand, if they cannot overcome their impasse of original problem, they lead to efficient learning by learning again focusing on their origin of the impasse.

"The Problem Simplification Strategy" has two functions which get learners to recognize the difference between the problem which they couldn't solve and the problem which they could solve. One is "the Difference Extract Function", and the other is "the Difference Connect Problem". We describes these functions in 3.2 and 3.3.

3.2 Difference Extract Function

In problem simplification strategy, the learning environment sets learners simpler problem by only one step when they cannot solve a problem. If they can solve the simpler problem, they tackle again the original problem by only one step. Since the simplified problem which a learner could solve and original problem which a learner couldn't solve have strong relationship, they are expected to tackle the original problem using simplified problem. However, for this purpose, they need to recognize the relationship of the problems. Therefore, by lining up the simplified problem which a leaner could solve and the original problem which a learner couldn't solve and highlighting difference between those, the learning environment has learners be conscious of the difference. This function is called "a Difference Extract Function". By using this function, the learners may be able to be not only aware of difference between the simplified problem which they could solve and the original problem which they couldn't solve, but also may be able to solve the original problem by using simplified problem.

3.3 Difference Connect Problem

We can assume that there are learners who cannot overcome the impasse in solving the original problem, even if they use "a Difference Extract Function". In this case, the learning environment set them "a Difference Connect Problem". This problem is a problem which connects the simplified problem which they could solve and the original problem which they couldn't solve.

It is assumed that a problem which a learner couldn't solve has a part which they cannot solve somewhere in a solution. Because the difference connect problem has such part as a solution of this problem, this problem is a problem which connects a solution of problem which a learner could solve and a solution of problem which a learner couldn't solve. The solution of this problem is generated by taking the difference of the solution of problem which a learner could solve and problem which a learner couldn't solve, i.e., solution structure of problem which a learner could solve and problem which a learner couldn't solve. Although the difference connect problem is one of a partialized problem, unlike usual partialization, partialization in generating the difference connect problem is performed so as to focus on the part which they cannot solve in a solution. We assume that if learners recognize where the part as their origin of the impasse is and connect this part and problem which they could solve, they can solve problem which they couldn't solve. If learners cannot overcome their impasse in solving problem which they couldn't solve through "Difference Extract Function", the learning environment sets them "a Difference Connect Problem".

If learners cannot solve "a difference connect problem", this problem is specialized/ partialized based on "Problem Simplification Strategy". By repeating this, they can find the part which they cannot solve more appropriately.

There are three kinds of the difference connect problem as follows. In case the relation between problem which a learner could solve and problem which a learner couldn't solve is partialization and expansion, the difference connect problem is (1) a problem whose solution is lost by partialization (Figure2). In case the relation between problem which a learner could solve and problem which a learner couldn't solve is specialization and generalization, the difference connect problem is (2) a problem which have learners derive attribute omitted by specialization (Figure3 (a)), and (3) a problem which have learners use operational relation changed by specialization (Figure3 (b)).

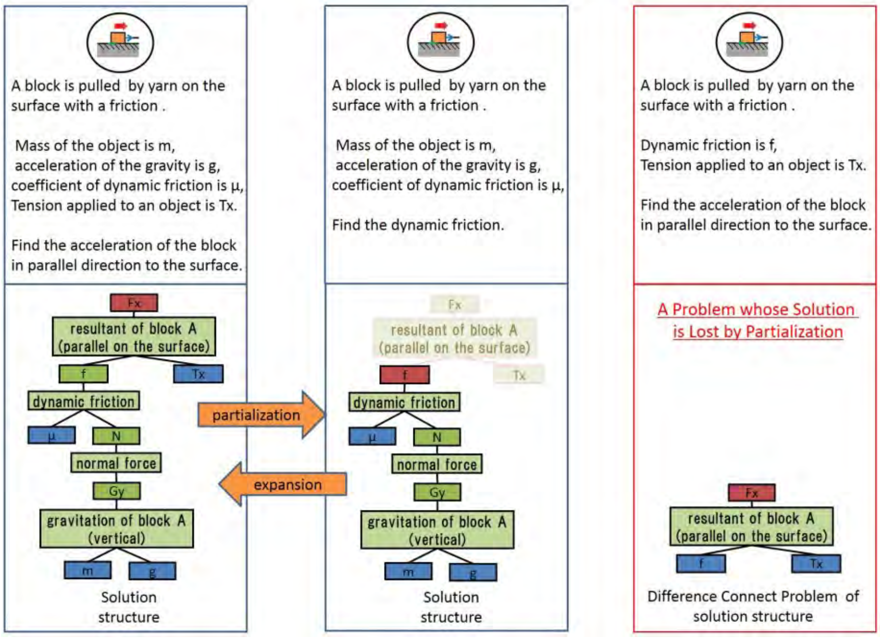

Figure 2. A Difference Connect Problem in Case the Relation between Problem which A Learner could solve and Problem which A Learner couldn't solve is Partialization and Expansion.

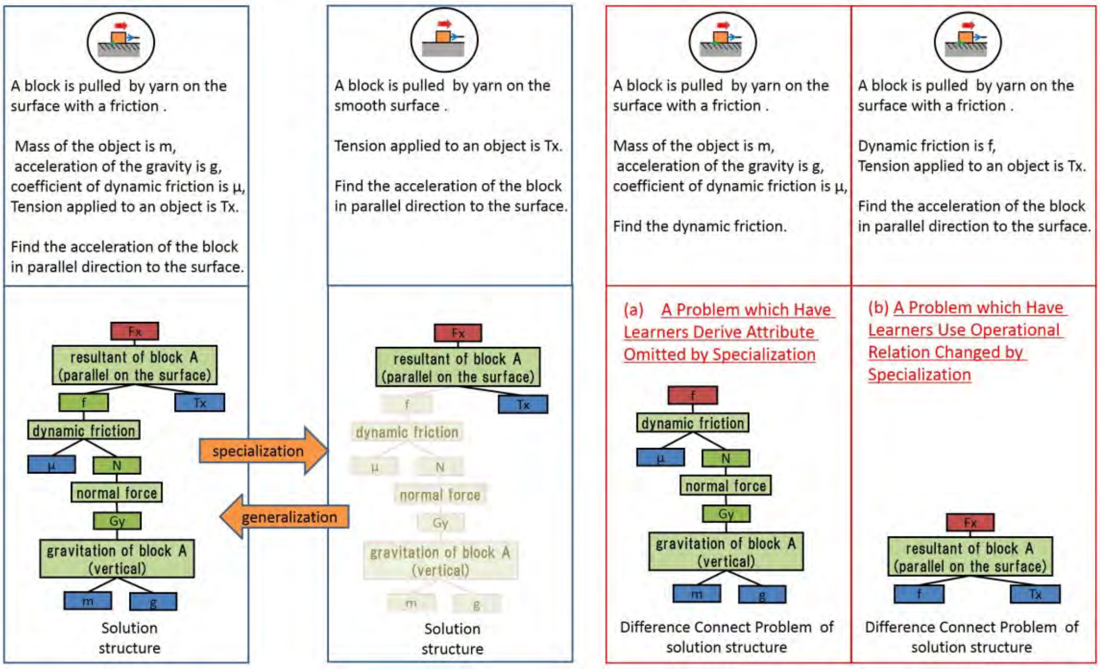

Figure 3. Difference Connect Problems in Case the Relation between Problem which A Learner could solve and Problem which A Learner couldn't solve is Specialization and Generalization.

3.4 Support System for Self-overcoming of Impasse

We had created support system for the self-overcoming of impasse. This system is a system which performs a problem exercise that a natural situation for taking the difference into consideration by "Problem Simplification Strategy". This system has first problems and can automatically generate simplified problems. This system is implemented on a tablet PC that excels in carrying and been able to use anywhere, taking it into consideration that this system is used at actual schools.

Firstly, learners select a first problem prepared by this system which they should tackle. It is desirable that this problem be a little difficult for the learners. If they cannot solve this problem, they can systematically simplify (specialized/partialized) this problem by only one step based on "Problem

Simplification Strategy". And so, if they can solve simplified problem, the difference extract function get them to pay attention to a difference between problem which a learner could solve and problem which a learner couldn't solve. This difference is the origin of the impasse in solving problem and this system specifies this difference. Then, they tackle again the original problem which a learner couldn't solve and aim to overcome an impasse of solving the problem by only one step. Then, if they cannot solve the original problem once more, this system sets them "a Difference Connect Problem". If they can solve this problem, they tackle again the original problem. If they cannot solve "the Difference Connect Problem", they can simplify (specialized/partialized) this problem based on "Problem Simplification Strategy". Repeating this flow, this system encourages learners to learn with them considering the difference between problems.

On this system,

(1) If learners cannot solve a certain problem, this problem is simplified.
(2) After learners can solve simplified problem, through "a Difference Extract Function" or "a Difference Connect Problem", they tackle the original problem.
(3) Learners can solve the original problem.

While the above a series of activities, this system only sets learners problems, not teaching how to solve. Furthermore, since learners overcome the problem which they could not solve once, when such activity has been seen, it is assumed that the self-overcoming of impasse has been done.

4. Practical Using Targeting National Collage Students

4.1 A Purpose and Method of Practical Using

We had used the system in class of dynamics at National Collage in a period. This purpose is that we confirm, from a questionnaire and a log, whether "a Problem Simplification Strategy" used by this system is valid support for the self-overcoming of impasse in actual school or not.

The subjects are freshmen of National College of maritime technology. They are 130 people in three classes. A method of practical using is as following;

(1) operation explanation of a system (10 minutes)
(2) system exercise (20 minutes)
(3) post-questionnaire (10 minutes)

The post-questionnaire is shown in Table 1.

We prepare three problems as first problems. These problems are checked by learners' teacher and are got his assent.

Table 1: The post-questionnaire for learners.

No.	Question
(1)	Do you like mechanics?
(2)	Are you good at mechanics?
(3)	Do you think that this exercise is useful for learning of mechanics?
(4)	Solving the problem which was set after answering correctly, did you use the problem which you could solve as a reference?
(5)	Was the problem that was set after making a mistake easier than the problem you mistake?
(6)	Was solving the problem that was set after making a mistake useful for solving the problem you made a mistake?
(7)	What was especially a good point of this system, you comparing this system with exercise books that you have used in the past?
(8)	Did it make your motivation to tackle the problem exercise increase that you can select the problem to solve next?
(9)	Were you easy to use this system?
(10)	Did using this system make your impression of the mechanics better?
(11)	Do you want to go on such exercises in the future?

4.2 A Result

We used 103 persons' data as valid data, excluding the subjects who cannot be identified from the log and who have a defect in a questionnaire. The result of post-questionnaire is shown in Figure 4. For each item, we treated "I think so very much" and "I think so" as a positive opinion, and "I do not think so" and "I do not think so much" as a negative opinion. We done sign test for each item. This result is that there is no significant difference in question No.10, a significant difference in No.9 ($p < 0.05$), and there are significant difference in the others ($p < 0.01$). In question No.7, there are 33 learners who described contents that they grasp the intent of the exercise. Except the question No.10, questions are positive opinions about this system and are statistically significant. About the question No.10, considering many learners feel reluctant in learning mechanics and this practical using is in only a period, we can interpret this result that about 40 percent of the learners had changed the impression of mechanics by using of this system as not a negative result for this exercise.

Counting the log in valid data, the total number of problems which this system set is 2432. 360 of these are problems which learners could solve, 1899 of these are problems which they couldn't solve, and remaining 173 problems are problems which were not marked because of the time-out and which had a system trouble before marking. And so, there were 53 kinds of problem which the learners had tackled. The average time in which learners tackled a problem was 46.98 seconds (*SD* = 82.25). There are 23.61 problems which a learner had tackled (*SD* =13.09). We can say that learners can tackle many problems. This is because, we assume, how to tackle one problem depends on learners, e.g. tackling the same problem repeatedly or simplifying problem which they cannot solve. In addition, we assume that the average time in which learners tackled a problem is slightly short because of not taking time so much while resolving a problem which they couldn't solve. Besides, we assume that three first problems prepared by us are the problems of suitable difficulty for learners because they cannot solve all first problems.

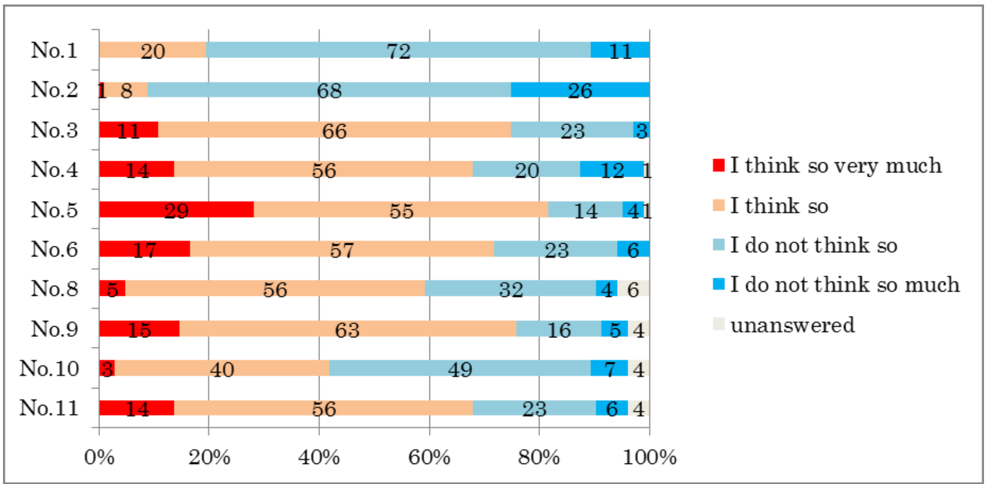

Figure 4. The Result of Post-questionnaire.

4.3 A Learners' Type Classification

We classify a learner's behavior by these features from log data. We call learners who had done the self-overcoming of impasse in "Problem Simplification Strategy" "learners having done the self-overcoming of impasse", learners who had recognized their challenge by finding problem which they can solve "learners having revealed a challenge", and learners who hadn't solved any problems "learners not having solved any problem". Each learner's distribution is shown in Table 2.

There are 29.42 problems which a learner in "learners having done the self-overcoming of impasse" had tackled (*SD* =11.22). (The breakdown of this is as follows; the average number of problems which he/she could solve is 5.29 (*SD* =2.87). The average number of problems which he/she couldn't solve is 22.37 (*SD* = 9.56). The rest are problems which were not marked because of the time-out and which had a system trouble before marking.) The average time in which learners tackled a problem was 38.14 seconds *(SD* = 60.52). There were 6.65 kinds of problem which the learners had tackled *(SD* = 2.61). The ratio of these learners is 60%, and they are learners who had done the self-overcoming of impasse as defined in this research. Because this system only set learners problems in this problem exercise, we assume that their solving problem which they couldn't solve is that they could do the self-overcoming of impasse. Since the 60 % of whole learners could do such activity, we assume that the expected effect of support for the self-overcoming of impasse using "Problem Simplification Strategy" is demonstrated. The number of problems which "learners having done the self-overcoming of impasse" had tackled is also more than one of the other learner groups.

There are 19.86 problems which a learner in "learners having revealed a challenge" had tackled (*SD* = 11.03). (The breakdown of this is as follows; the average number of problems which he/she could solve is 1.60 (*SD* =0.92). The average number of problems which he/she couldn't solve is 16.34 (*SD* =9.73). The rest are problems which were not marked because of the time-out and which had a system trouble before marking.) The average time in which learners tackled a problem was 58.45 seconds (*SD* = 82.33). There were 6.34 kinds of problem which the learners had tackled (*SD* = 2.66). The ratio of these learners is a little over 20%. Because these learners couldn't do the self-overcoming of impasse, the average number of problems which they could solve for them is less than one for "learners having done the self-overcoming of impasse". Since "Learners having revealed a challenge" could solve a certain problem, it can be said that they have knowledge required to solve this problem and can use it. Then, it can be said that the difference between problem which they could solve and problem which they couldn't solve is the challenge to be overcome for the learners, and besides, this challenge for the learners have been elicited. We can't suggest that it is effective for the learners to overcome this point by using our system clearly because our system doesn't teach them how to overcome the challenge for them. However, we suggest that the problem exercise using "Problem Simplification Strategy" is useful for these subjects in order to clarify the challenge. Also, we insist that it is important to expand the functions which teach them directly so that they overcome their challenge as necessary.

There are 9.47 problems which a learner in "learners not having solved any problem" had tackled *(SD* = 7.24). (The breakdown of this is as follows; the average number of problems which he/she couldn't solve is 8.31 (*SD* =6.59). The rest are problems which were not marked because of the time-out and which had a system trouble before marking.) The average time in which learners tackled a problem was 111.43 seconds (*SD* = 185.83). There were 3.36 kinds of problem which the learners had tackled (*SD* =1.49). The ratio of these learners is a little under 20%. We can consider them as students which don't have the basic knowledge of mechanics. "Problem Simplification Strategy" has the aims of the promotion of understanding the relationship between problems for the student with the knowledge required to solve this problem. "Learners not having solved any problem" must have been taught the knowledge required to solve this problem by classes. However, we can presume that they don't have the knowledge or they cannot use the knowledge for solving problems. Therefore, we can't suggest that it is valid for them to perform this problem exercise. However, we suggest that it is indirectly valid for them to perform this problem exercise because of suggesting that they need a method of learning other than problem exercise. Although outside the scope of this research, it is also important to teach such learners when we consider the overall support of learning of mechanics. Besides, we can consider that we can integrate teaching such learners with our problem exercise with an affinity.

From the above, we confirmed the self-overcoming of impasse through this practical using. However, we still haven't demonstrated a learning effect of this strategy. So, we need to confirm it in the future issue.

Table 2: A Learners' Type Classification.

A learners' type classification.	The number of people	The ratio of the whole
Learners having done the self-overcoming of impasse	61	59.22%
Learners having revealed a challenge	23	22.33%
learners not having solved any problem	19	18.45%

5. Conclusion and Future Issues

In this paper, we suggest "Problem Simplification Strategy" as support for the self-overcoming of impasse. This is a way to aim to do the self-overcoming of impasse by learner's dividing a problem into the part that can be solved and not solved. We designed and developed support system for the self-overcoming of impasse implemented this strategy. Besides, we had done a practical use of this system in classes of a technical high school. This result shows that this strategy can use as problem exercise and is valid as support for the self-overcoming of impasse because the ratio of "learners having done the self-overcoming of impasse" is 60%. Our main future works are (1) verification of the learning effect of the scaffolding with problem simplification by comparing with the usual problem exercise and (2) design of a fading method of the scaffolding.

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