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An Interactive Environment for Learning by Problem-Changing

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Abstract: To make a new problem from the original one and to compare their solutions are promising activities to promote a learner to be aware of the structure of these problems. Especially for knowledge-rich problems like word problems in arithmetic, mathematics or physics, this awareness is very important to master the use of solution methods. To realize such exercises in physics, we have developed a computer-based learning environment that allows a learner to make a new problem by changing the original one and that diagnoses the problem change. Preliminary evaluation of the learning environment has also been reported.

Keywords: Interactive Environment, Problem-Changing Exercise, Physics Learning

Introduction

An interactive learning environment for problem-changing exercise where a learner is required to solve and change the problems is described in this paper. In usual problem solving exercise, a learner works on to solve several problems by using solution methods that the learner has already acquired and has been mastering. In the exercise, a learner practices not only to execute the solution methods but also to recognize the semantic structure of problems in order to apply the solution methods [1]. Therefore, it is important for the learner to solve various kinds of problems with different semantic structures. Moreover, to realize effective learning during the problem solving exercise, it is important for the learners to be aware of the difference between problems [2, 3]. It is well-known that poor problem solvers are often unaware of the semantic structure of the problems from the viewpoint of problem-solving [5, 6, 7, 8]. Several researchers have already suggested that problem-changing by learners where a learner poses a new problem by changing the existing problem, is a promising method to promote them to be aware of the differences between problems [9, 10].

One of the most difficult issues to effectively realize such learning activity is the way to give feedback for the learner's problem changes. To give useful feedback, it is necessary to assess the problem change that is composed of an original problem, a new problem and their differences. If a learner has carried out this learning by him/herself, the learner is required not only to change and solve the problems but also to assess his/her problem change. It is often too difficult for the learners to complete these tasks. Although a teacher can able to assess the problem change and give feedback based on the assessment, taking care of several learners at a time is hard because the learners are usually allowed to change a problem in various ways. Mutual assessment by learners is a solution of this issue but to complete these tasks is not easy for the learners, especially for the beginners. We have investigated the function of automatic assessment of learner's problem-change to realize “problem-changing exercise” as a more common and useful learning method. We call the framework of the automatic assessment as “agent-assessment”, because the above-mentioned first assessment is often called as “self-assessment”, the second as “teacher-assessment” and the last as “peer-assessment”.

We have paid special attention for learning by problem-posing [11] and have already developed interactive learning environments for "solution-based problem-posing exercise with agent-assessment" in arithmetical word problems [12, 13]. On the other hand, we have investigated a model of exercise problems in physics and automatic problem generation based on the model [14]. In this study, we have proposed "learning by problem-changing" as an advanced style of "learning by problem-posing" and developed an interactive learning environment for the learning. In the next section, the framework of problem-changing exercise has been described by comparing problem-solving and solution-based problem-posing exercises. Then, implementation of a learning environment for the problem-changing exercise and the results of preliminary evaluation of the environment have also been explained.

1. Learning Environment for Problem-Changing Exercise

1.1 Framework of Problem-Changing Exercise

In this subsection, the framework of problem-changing exercise has been described by comparing problem-solving exercise and solution-based problem-posing exercise. In Figure 1, three types of exercise models are shown. In problem-solving exercise, a learner is required to solve several problems that can be solved by the same solution method. In this exercise, a learner has to find a structure that is necessary to apply a solution method in a problem. In solution-based problem-posing, a learner is required to pose problems that can be solved by the same solution method. This means that a learner has to compose the same structure in this exercise. Through these activities, it is expected that the learner can understand the way to use the solution method. Both exercises, however, include no direct activity to promote awareness for the differences among problems or solution methods.
In problem-changing exercise, a learner has been provided with a problem to solve it. The learner is required to make a new problem by changing the provided problem. Problem-1 in Figure 1(c) corresponds to the original one and Problem-2 or Problem-3 corresponds to the generated one. Because a learner makes the differences in problems by him/herself, the

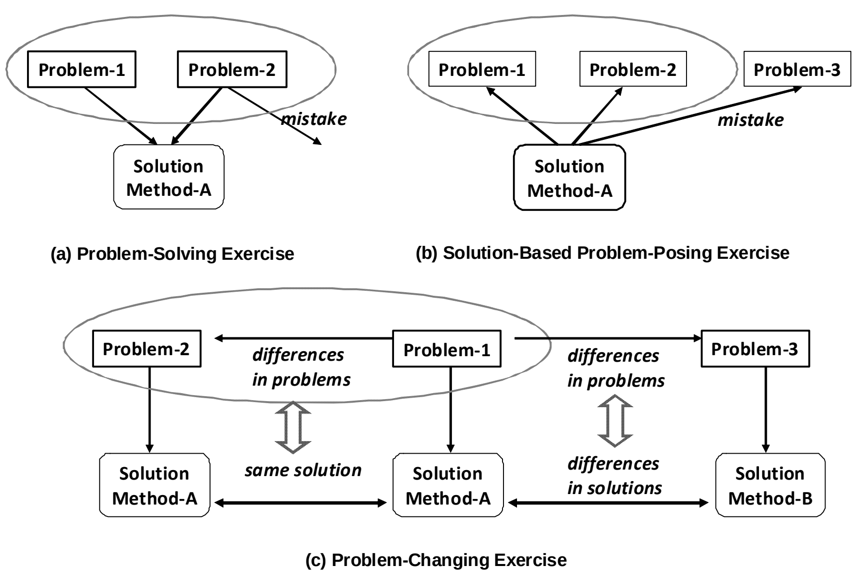

Figure 1. Three types of model exercises.

differences are well-known to the learner. The learner is then required to solve the generated problem. In this figure, Problem-2 is generated by changing Problem-1 but the same solution method can be applied. This means that the problem change does not have any effect to the solution method. For Problem-3, the different solution method has to be applied. This means that the problem change has some effects to the solution method. Through the comparison of problems as well as solutions, it is expected that a learner more clearly recognize the structures in the problems necessary to apply the solution methods.

1.2 Learning Environment

In this learning environment, a learner (1) solves a physics problem, (2) changes the problem, (3) solves the changed problem, and (4) compares the two problems and solution methods. The learning environment provides with an interface where a learner can solve and change the problems. The learning environment is to diagnose the problem-solving and problem-changing, and then give feedback based on the diagnosis. In this subsection, these steps are explained.

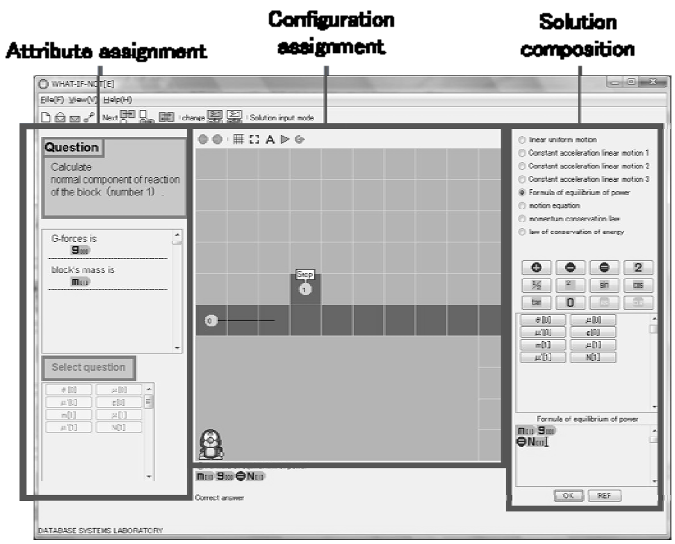

Figure 2. Interface of Learning Environment of Problem-Changing Exercise.

1.2.1 Interface of Problem-Solving and Problem-Changing

Figure 2 shows the interface of problem-solving and problem-changing in the learning environment. A problem is specified in the "attribute assignment" area and "configuration assignment" area. In the configuration area, the physical components and their relations are assigned. Both related attributes that are necessary to solve the problem and their statuses whether the attribute values are given or not, are assigned in the attribute assignment area. Solution of the problem is composed in "solution composition" area. In the area, a learner selects a formula from a list of formulas. Then the learner concretes the formula by using several attributes and calculation components provided in the solution composition area. When the learner completes the input and pushes the diagnosis button, the learning environment diagnoses the formula expression.

After a learner correctly solves a problem, the learner is required to change the problem for the next task. The problem change is carried out in the same interface. In the configuration area, the learner can change the components and relations between them. In the area, several physical components are prepared as icons and add the current configuration by drag&drop operation. Components in the current configuration can be deleted and changed the location. Then, from a list of attributes in the new physical situation, learner decided status of the attributes in the new problem, that is, given attribute and required attribute (the answer of the problem). The learner is then required to solve the new problem generated by the problem change in the same way with the original problem. The diagnosis and feedback for the problem-solving and problem-changing are explained in 1.2.2.

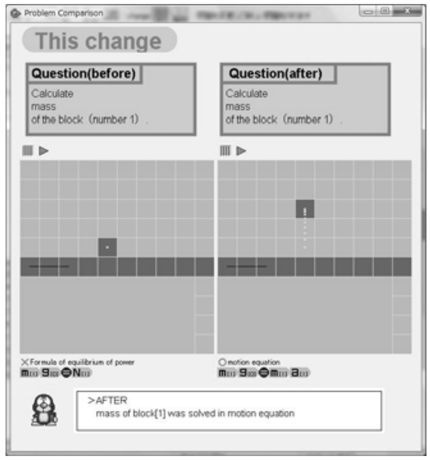

Figure 3. Interface for Problem Comparison

1.2.2 Problem Comparison

After solving the new problem, learner examines the difference between the problems and the solutions in the problem comparison interface as shown in Figure 3. In the interface, sentence of the original problem and the changed one is shown at the upper part of the interface. The situations of the problems are shown in the middle. In the lower part, learning environment presents the solution methods that are applied to solve the problems.

1.3 Diagnosis and Feedback

1.3.1 Internal Description of Problems

Internal description of problems is composed of (1) situation description, (2) attribute status, and (3) solution method. Situation description is composed of attributes exist in the physical situation in which the problem is included with the numerical relations among them. Attribute status specifies whether the attribute value is given, required or unknown in the problem. A problem is defined by specifying given value attributes and required value as one. Solution method is the procedure to derive the required value from given values by using the numerical relations among the attributes included in the situation. Therefore, solution method can be derived automatically by the situation description as well as attribute status. The framework to describe problems in physics have been proposed by the authors and used for problem sequencing or problem generation [15, 16, 17].

In this framework of the problem description, the problem change is categorized into two types, (1) attribute status change in the same situation, and (2) situation change. If there is a change in the same situation, it is easy to deal with because all attributes and numerical relations have been prepared in the problem description. As for the situation change, it is necessary to restrict. The situations that can be deal within this learning environment are prepared as "microworld graph" beforehand [18]. A node of microworld graph is a situation and a link, which can be the possible change of the situation (the authoring of the graph has also been investigated continuously [19]). The microworld graph used in the learning environment consists of six components, that is, block, plane (smooth/unsmooth), slope (smooth/unsmooth), string, pulley, and external force. Then the number of the components and connection methods are also restricted. If the learner tries to compose unprepared configuration, it is not accepted by the environment.

1.3.2 Errors in the Environment and Feedback

In problem-solving phase, a learner often makes a mistake to compose a solution. Because the environment can solve the problem, the error can be detected by comparing a correct solution. As for an error in the problem-solving, it is indicted directly and the correct one is explained.

In problem-changing phase, (1) unacceptable configuration, (2) errors in attribute status are detected. Unacceptable configuration is not an error, but if a learner tries to make an unprepared configuration, the environment informs the learner that it is unacceptable. Errors in attribute status are the case that a learner makes an unsolvable problem. When a physical situation is accepted by the environment, an error is interpreted as a lack of some given attributes. Hence, the environment points out that the problem can not be solved, and suggests the learner to add a few given attributes. Even if the problem is solved, there are sometimes unnecessary given attributes in the attribute status. The learning environment points out the existence of unnecessary given attributes, and suggests the learner to find and delete them.

2. Experimental Use

Since there is no similar technology-enhanced learning environment that supports problem-changing exercise, the main purpose of this experimental use is to confirm whether the exercise can be carried out in the environment or not. We also examined the learning effect of the exercise by measuring between pre-test and post-test comparing the experimental group with the control group. Through the analysis of the results, we have concluded that the learning environment is promising.

2.1 Procedure of Experimental Use

The experimental group took the pre-test for five minutes one day before the experimental use. The subjects were explained about the way to change and solve problems in the environment. The subjects are then asked to carry out problem-changing exercise for twenty minutes. Just after the use, subjects took the post-test. As for the control group, the subjects were required only to solve physics problems with the learning environment where only the problem-solving step was available. We prepared two different tests and half of the subjects in each group took one test in the pre-test and the other in the post-test, then the other half of the subjects took the tests in reverse order. Questionnaire was carried out just after the post-test. The subjects were undergraduate students in the engineering division. Available data are twenty-one in the experimental group and fifteen in the control group.

2.1.1 Analysis of Log Data and Questionnaire in the Experimental Group

In the problem-changing exercise for twenty minutes, a subject was requested to diagnose his/her problem changes 5.8 times in average. This means that a subject makes one new problem in every 3.4 minutes. More than half of the problem changes (58%) included errors, but almost half of the errors (46%) found in the solution description. Because we have already confirmed that the subjects have enough ability to solve the same level of physics problems and the frequency of errors decreased gradually in the exercise, we guess that the main reason of errors in the solution description was the difficulty and lack of experience of the operations in the learning environment.

The results of the questionnaire are shown in Table 1. Two third of the subjects agreed that this exercise was interesting. More than two third of the subjects agreed that the problem-changing exercise with the learning environment was more effective to comprehend the relation between problems than usual problem-solving exercise, though more than half of the subjects disagreed this learning environment was easy to use. These results suggest that the problem-changing exercise realized with the learning environment is promising although it is necessary to improve the learning environment from the viewpoint of usability.

Table 1. Results of Questionnaires.

	Strongly Agree	Agree	Disagree	Strongly Disagree
The software is easy to use.	1	8	11	1
The exercise with the software is more effective to comprehend the relations between problems than usual problem-solving exercise.	1	14	5	1
The exercise with the software is interesting.	4	10	6	1

2.2 Results of Pre-test and Post-test

2.2.1 Explanation of the tests

There is no standard way to evaluate the learning effects of the problem change. As a measurement in this research, a subject was provided with six problems and requested to describe the relations between them on paper. Figure 4 is an example of the provided problems. Each problem was labeled by an alphabet. In Figure 4, "A" in the left upper part is the label. Figure 5 shows an example of the description of the relations. The subjects were instructed to describe the relations in two ways, that is, one way is to connect two problems by a link and to give explanation about the link, and the other way is to enclose several problems and to give the explanation about the group. Each link and group is counted as one relation. If the explanation refers to solution method and if it is correct, the relation is counted as a solution relation. "Both problems are solved by equation of motion" is an example of the solution relation. Both "a string is contained in both problems" and "the number of objects is different" are counted as total relations but not counted as a solution relation. Here, we assumed that if this exercise promoted the subjects to be aware of the structure of the problems from the viewpoint of solution, the number of the solution relations was expected to increase.

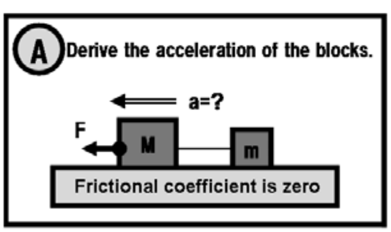

Figure 4. A Problem in the Test.

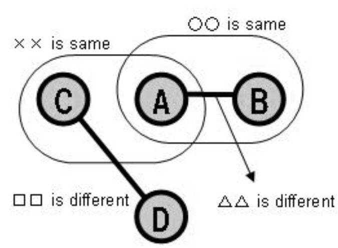

Figure 5. A Sample of the Description.

2.2.2 Analysis of the Results

The results of the experiment are shown in Table 2, Figures 6 and 7. As for the number of solution relations, although there was no significant difference between the experimental group and the control group in the pre-test (two sided p-values from Mann-Whitney test with correction for ties, p=0.41), there was a significant difference in the post test (p=0.048). Besides, there was a significant difference in the numbers of the solution relations between the pre-test and the post-test in the experimental group (p=0.003), and marginal significant difference was found in the control group (p=0.06). These results suggest that although both exercises improved the subjects' awareness for problem structure from the viewpoint of problem-solving, the problem-changing exercise was more effective than the problem-solving.

As for the total number of relations, there were no significant differences between the experimental group and the control group both in the pre-test (p=0.18) and post-test (p=0.16). Besides, there was no significant difference in the numbers of the total relations between the pre-test and the post-test in the experimental group (p=0.12) though there was a significant difference in the control group (p=0.004). These results suggest that the subjects in the experimental group focused more on solution relations than the subjects in the control group. While this experimental use is a preliminary one with the limitations on the number of subjects and the learning time, we found enough results to judge the problem-changing exercise is promising.

Table 2. Results of the Experiment.

	Solution relations		Total relations	
	Pre-test	Post-test	Pre-test	Post-test
control group (n=15)*	0.3(0.46)	0.6(0.40)	2.2(1.61)	5.2(2.80)
experimental group (n=21)*	0.2(0.51)	1.5(1.66)	3.3(2.10)	4.10(1.87)
p-value	0.41	0.048	0.18	0.16

*Average scores

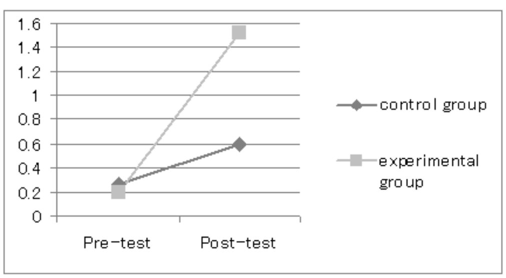

Figure 6. Numbers of Solution Relations.

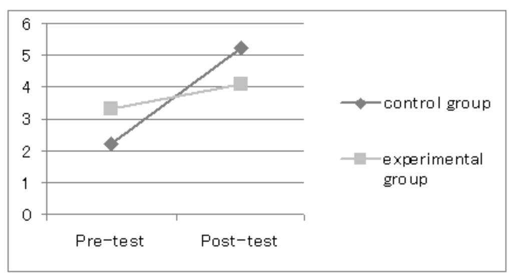

Figure 7. Numbers of Total Relations.

3. Conclusions

In this study, we have designed and developed an interactive learning environment for learning by problem-changing with a target to learn physics. Although several investigations have already suggested that problem-changing is as effective as a learning activity, it is not easy for teachers or learners to realize the learning in usual classroom situation. The main difficulty is related to the way in assessing the problem change. However, the learning environment we have developed includes the function to assess the problem change automatically. We call this kind of assessment as "agent-assessment". Through a preliminary evaluation of the learning environment, the problem-changing exercise in the learning environment promoted the subjects to be aware of the relations between problems from the viewpoint of solution methods. Because the current environment is a kind of prototype one that deals with only a small number of problems, the experiment was also preliminary one. Our future works, therefore, to focus on sophistication and expansion of the environment and to carry out larger size experiment including more subjects and increase in learning time.

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