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A Support System for Learning Physics in Which Students Identify Errors Using Measurements Displayed by a Measurement Tool

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Abstract: It is sometimes challenging for learners of elementary physics to correct their mistaken notions regarding physics concepts. The need to address this phenomenon is illustrated by the existence of common misconceptions such as ‘motion implies a force’ (MIF), in which learners mistakenly believe that force always acts in an object’s direction of motion, as well as educational approaches using error-based simulation (EBS). In a conventional EBS, a learner’s mistake is usually output as a physical phenomenon, but there are cases in which the learner’s mistake cannot actually be shown. For this reason, we propose an EBS in which measurement information is displayed to the learner in the form of a measurement tool together with the physical phenomenon and shows error in response to the learner's mistake, something the conventional EBS is unable to do. In this paper, we propose an EBS learning exercise using a measurement tool in which the learners themselves must determine the measurement in order to confirm the correct answers. Using this method, it is possible for the learner to use trial and error after getting the wrong answer and eventually find the correct answer. It is also possible to support learning in a virtual experiment environment using a computer. Experiments were performed using a system equipped with the measurement tool, and it was verified that the learners made significant progress learning physics through trial and error.

Keywords: elementary physics education, error visualization, learning support system

1. Introduction

In elementary physics education, learners are often taught mechanical concepts related to phenomenon that they themselves have experienced. The learner thus grasps the concept together with the phenomenon. However, sometimes learners may understand the phenomenon but misunderstand the concept, such as erroneously thinking that force always acts in the direction of motion. It may be difficult for teachers to correct this mistaken understanding through mere verbal explanation during a traditional classroom lecture (Clement, 1982; Hirashima, Shinohara, Yamada, Hayashi & Horiguchi, 2017).

Therefore, it is more effective for learners to combine the learning of physics concepts with actual observation of physical phenomena through the use of experiments. It has been reported that generating simulated physical phenomena on a computer system based on physics problems solved by learners using error-based simulation (EBS) is an effective approach for making learners aware of their mistakes. In a study using a virtual experiment environment, learners learned about physics concepts by selecting a formula for obtaining a certain value and obtaining a value to be used for the formula.

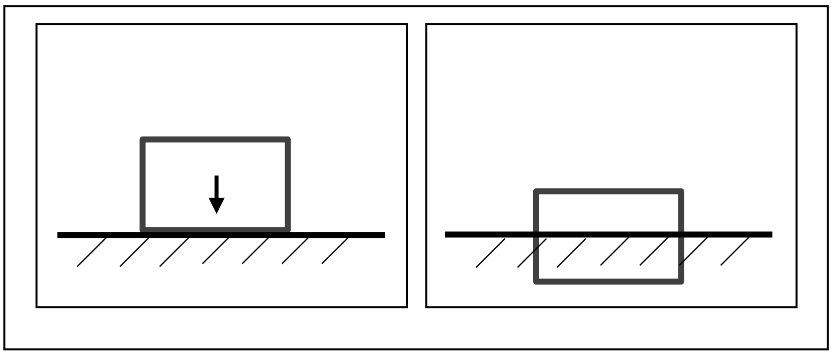
A method was previously proposed for visualizing learners’ mistakes by outputting the parameters of load and speed in addition to the observable phenomenon to learners who then attempted to identify the cause of the error based on criteria for error-visualization (CEV) of phenomena (Horiguchi & Hirashima, 2000; Horiguchi & Hirashima, 2001), and to aim at recognition of errors by learners themselves, because there are difficult answers to visualize by using phenomena in learning using EBS. In this paper, we propose a learning support system in which EBS is combined with a measurement tool and learners use trial and error to determine the magnitude and direction of forces acting on an object. Specifically, the learner is asked to draw force vectors (arrows) for all the forces acting on the object and then observe whether the correct behavior is produced. In addition, learners can set a measurement tool and observe a parameter after inputting the forces using an EBS. This enables them to investigate the parameters displayed on the measurement tool in response to their own errors, to confirm the parameters related to their error as well as the correct parameters, and to grasp physics concepts by connecting these parameters with the simulated phenomena. The learning environment not only provides the environment for measurement tool operation, but also diagnoses learner's behavior and provides the learner with feedback to support the install to measurement tool, and aiming for error-reflection as with the EBS(Hirashima, Noda, Kashihara & Toyoda, 1995; Hirashima, Horiguchi, Kashihara & Toyoda, 1998). We also conducted a preliminary experiment using the proposed system and evaluated how effective it was in improving learning outcomes.

The remainder of this paper is organized as follows. Section 2 describes the EBS, Section 3 describes the use of the measurement tool, Section 4 describes the proposed system, Section 5 provides an evaluation of the experiment, and Section 6 summarizes the work and presents the conclusions.

2. Learning Elementary Physics through Error-Based Simulation

Imai et al. (2008) conducted a study on EBS in which the solution to a force equation was simulated by a drawing. In this EBS, the learner inputs a force, which then acts on the object as represented by an arrow. The system simulates the conditions corresponding to the force that the learner input, and provided there is no error, the correct phenomenon will be displayed. However, if there is an error, an unnatural phenomenon will be simulated instead. For example, in the case of forces acting on a stationary object on the floor (i.e., a downward gravitational force and an upward ground reaction force equal to the gravitational force), when the learner inputs only the downward gravitational force, as shown in Fig. 1 (a), a simulation of the object falling through the floor is generated, as shown in Fig. 1 (b). In this paper, we demonstrate that it is possible to use EBS with a measurement tool to teach the concepts of static systems to junior high school students, and that this system can be used by the students themselves to grasp the concept of Newton’s third law of motion through trial and error and retain the acquired knowledge. This learning activity using EBS support the error-visualization important for problem solving, also makes it possible for discovery learning through behavior.

Shinohara et al. (2016) used EBS to conduct lessons on the concepts of motion, velocity, and acceleration and verified the effectiveness of the system in improving students’ learning outcomes.



(a) Student’s Incorrect Answer *(b)* EBS’s Output

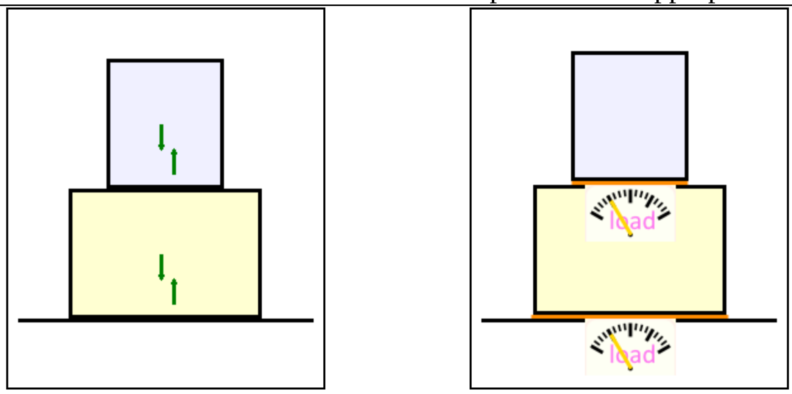
Figure 1. EBS System Concept

3. Use of a Measurement Tool to Indicate Parameters

In an EBS that simulates the behavior of an object in response to force, the simulation may show the correct answer even when the learner erroneously answers due to the resultant force being equal to the correct force when the object is at rest. In such cases, despite the solution seeming to be correct, the learner may still be able to notice their error by looking at the differences between the parameters they input and those of the correct answer.

Another technique has been proposed, in which the values of parameters such as speed and load are visualized using a measurement tool. The authors previously studied a learning support system designed to explore whether it is possible to visualize errors corresponding to learners' input. The system displays a measurement tool to visualize errors when parameters meeting certain conditions are input (Ueno, Tomoto, Horiguchi & Hirashima, 2018).

Figure 2 (a) shows an example of an erroneous answer from a learner who thought that a measurement tool showing the value of a load was an effective form of feedback. Figure 2 (b) shows output in the form of a measurement tool displaying the load. The size of the output parameter is decided based on the force vectors input by the learner and their size and magnitude relations. In the incorrect answer shown in Fig. 2 (a), there is no external force applied to the lower object from the upper object. Therefore, when weight measurement tools are installed, as shown in Fig. 2 (b), the measurement tool corresponding to the lower object displays the weight as being less than the correct value. The system determines what should be observed and provides the appropriate output.



(a) Erroneous Answer *(b) Output from a Measurement Tool*

Figure 2. Example of Students' Answers and Output from a Measurement Tool

3.1 Criteria for Error-Visualization (CEV)

Horiguchi et al. (2001) use CEV to explain whether it is possible to understand the differences between correct and incorrect motions in an EBS. In CEV, the difference between the speed of the incorrect motion and that of the correct motion is calculated as "CEV 1" and the difference between the acceleration of the incorrect motion (first derivative of velocity) and that of the correct motion is calculated as "CEV 2". It is possible for a learner to notice an error when the visualization condition of either CEV 1 or CEV 2 is satisfied, although it is easier when only CEV 1 is satisfied than when only CEV 2 is satisfied. It is also easier to notice an error when both conditions are satisfied than when only one of the two is satisfied.

An example of a motion equation problem using EBS is shown in Fig. 3, and a part of the output generated from the equation shown in Fig. 3 at a specific numerical value is shown in Table 1.

In the simulation corresponding to Eq. (B), the block ascends the slope, which is obviously different from the correct behavior corresponding to Eq. (A). The correct and incorrect answers are positive and negative, respectively, and the values of velocity and acceleration satisfy both CEV 1 and CEV 2.

In the simulation corresponding to Eq. (C), the block descends the slope, which is the correct behavior, but the velocity of the block decreases when θ is increased. This behavior is the opposite of what should happen. If the learner recognizes that the block should move faster when the slope is steeper, it is effective for them to observe a condition in which a parameter, namely, inclination, is changed. In this case, because only the acceleration of the block is different, the answer is incorrect and satisfies only CEV 2. Similarly, for the solution to Eq. (D), it is effective to generate and observe a simulation in which θ = 0 because the block is stationary under the correct conditions (velocity has a value of 0), but the conditions corresponding to Eq. (D) cause the block to move to the left (velocity is positive). In this case, Eq. (D) is an incorrect answer and satisfies both CEV 1 and CEV2 when θ = 0.

As in the above example of the equation of motion, Table 2 shows the conditions for visualizing the solution to the problem shown in Fig. 2 (a). The simulation of both correct answers and incorrect answers is stationary and there is no apparent difference, that is, the rate of change is 0. Such erroneous answers are examples of cases where it is not appropriate to give the learner feedback from a conventional physics EBS.

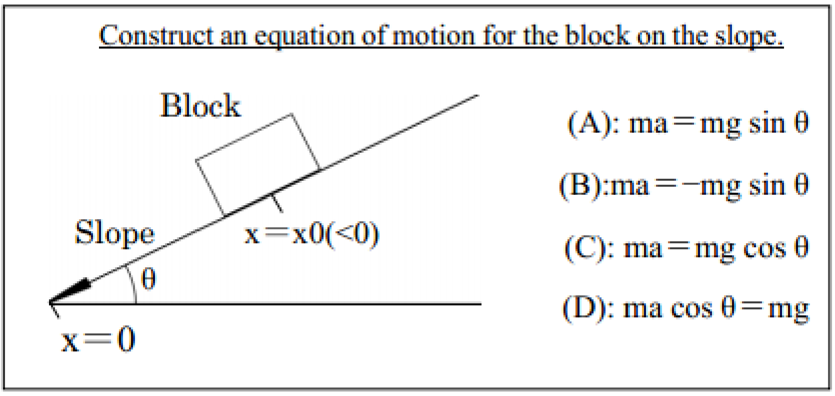


Figure 3. Example of Problem using Equation of Motion

Table 1

CEV Corresponding to the Equation of Motion

formula	Movement of the block (qualitative value)	Acceleration with increasing θ, 0 < θ < π/2	Acceleration at θ = 0
(A)	down the slope (+)	Increasing (+)	a=0 (0)
(B)	up the slope (−)		
(C)	down the slope (+)	Decreasing (−)	
(D)	down the slope (+)	Increasing (+)	a=g (+)

Table 2

CEV Corresponding to Two Stationary Objects

Answer	Movement of the block (value)	Feedback state
correct answer	stop (0)	feedback not required
Fig 2. (b)	stop (0)	feedback fails to indicate an error

3.2 Measurement tool output that responds to learner s' answers

We previously proposed a method for visualizing errors by displaying the parameters of load and velocity in addition to simulating the behavior of an object based on answers input by the learner. We have shown that it is appropriate to display the measured parameters in cases in which both the solution shown in Fig. 2 (b) and the simulation of the correct behavior and the erroneous answer for a moving object move in the same direction.

Figure 4 shows the diagnostic flow diagram based on the example in Fig. 2.

In the case when the answer results in the measured parameter being displayed, output is presented only in the form of behavior as in the conventional EBS. Output, including the measurement tool, is shown only after the learner confirms that the answer is incorrect and that there is no difference between the simulation and the behavior.

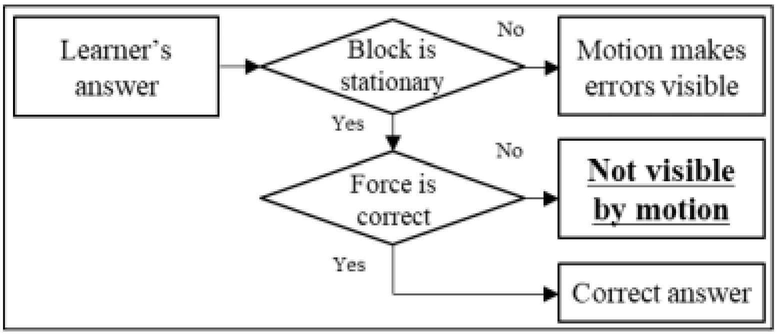


Figure 4. Classification of Learner's Answers in Two-Object Problems

4. Proposed System

In the previous study described in Section 3.2, the system outputs the parameters input by the learner, visualizing the errors with a measurement tool as feedback. In the method proposed in this paper, the measurement tool installation activity is directed as a method for noticing an error in the solution to the force equation through the learner's own trial and error. This is intended to lead the learner to discover the relationship between the force and the parameter's value displayed by the measurement tool and to understand the physics concept.

In the proposed method, the simulation is presented to the learner in the same way as the conventional physics EBS, and the force equation can be solved. After that, the learner installs the measurement tool for the simulation and the correct behavior corresponding to the answer input by the learner is output by the EBS, which confirms the parameters of load, speed, and acceleration applied to the behavior. The aim of these activities is for the learners themselves to use trial and error as they attempt to find the correct answer and decide whether to install the measurement tool.

In the support environment, in addition to the feedback by traditional EBS through behavior, it make feedback with measurement tool. Thereby, as in the case of the conventional EBS, it can be used as a supports the spontaneous discovery of an error for problem solving. This method enables learning effective for through behavior or parameter observations according to the situation. It can also be support the discover learning.

4.1 Virtual Experiment Environment to Support Learning by Designing Physical Experiments

In a previous study on the measurement tool installation problem, Tomoto et al. (2009) developed a virtual experiment environment for the proposed method in which a physics problem was devised. In this experiment, the learner was instructed to select a formula for obtaining a certain value and to obtain a value to be used for the formula from the measurement tool.

In this task, the behavior is presented in an experimental environment, and the value to be determined is specified. Next, a formula for obtaining the value is selected by the learner, and the value to be used in the formula is obtained from the measurement applied to the system's measurement tool. In this way, it is possible for the learner to learn how to apply an abstract formula they were taught to an actual system through a learning process in which the learner figures out the experimental method on their own.

4.2 Interface

The outline of the learning support system of the proposed method is shown using the example problem and the example error shown in Fig. 2. First, as shown in Fig. 5, the behavior is shown along with the problem sentence on the left screen, and the learner is instructed to answer the force equation by using the arrow on the right screen. After inputting the answer, the force behavior corresponding to the input answer is generated and the feedback is output as in the conventional EBS. In this case, the behavior corresponding to the error in Fig. 2 (a) generates behavior that is the same as the correct one. After that, the screen moves to the measurement tool installation screen shown in Fig. 6 (a) and prompts the learner to install the measurement tool in order to see the measurements of the behavior as well as the force, as shown in Fig. 6 (c). The measurement tool is displayed for both the correct behavior shown on the left side of the screen and the behavior corresponding to the answer input by the learner, and the value is visualized as a parameter based on each force. In the example shown in Fig. 6 (b), the measurement tool indicating load is placed directly under both objects, and if the parameters of the load applied to the object below are confirmed, it can be confirmed that the parameters corresponding to the answer input by the learner, which is shown on the right side, are smaller than those of the load in the correct behavior, which is shown on the left side, and that the parameters of the load in the behavior corresponding to the answer input by the learner are the same.

After the learner confirms the output, including that from the measurement tool, if there is an error in their answer, the system diagnoses whether the value displayed by the measurement tool corresponds to the parameter that changed in response to the error and evaluation the measurement tool based on CEV. When an appropriate measurement tool that can visualize the errors is installed, the learners are encouraged to pay attention to the measurement tool by giving them feedback stating that a measurement tool displaying errors has been properly installed.

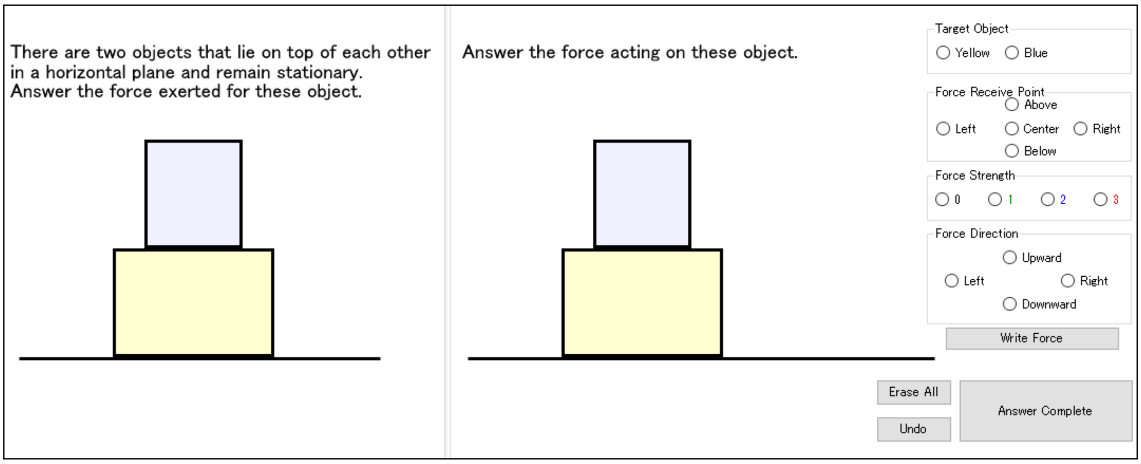
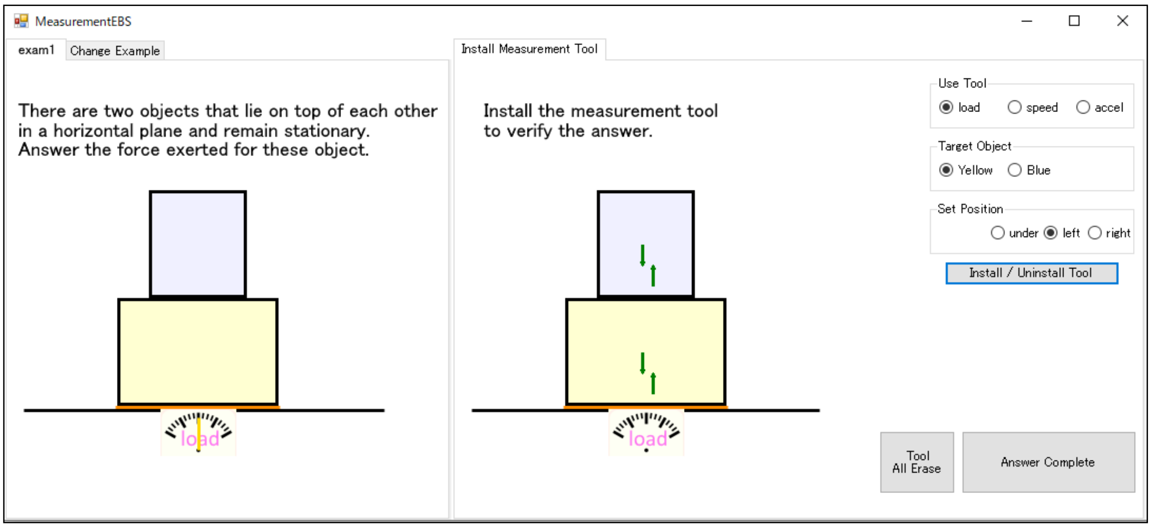
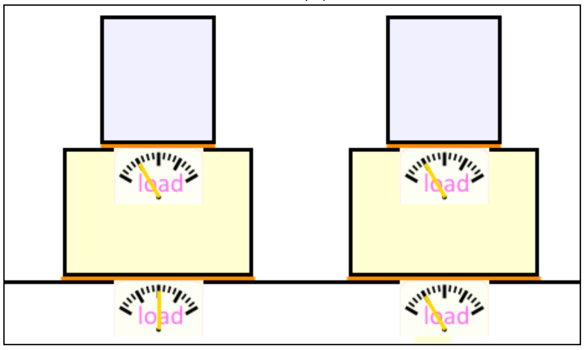


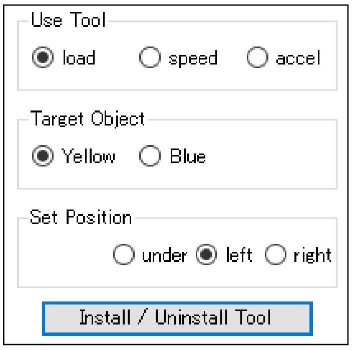
Figure 5. Force Answer Screen



(a) Measurement Installation Screen



(b) Installed Measurement Tool



(c) Selection Screen

Figure 6. Install Tool Screen

5. Evaluation Experiment

5.1 *Purpose*

In order to investigate whether this system contributed to the learners' understanding of elementary physics, the following experiments were conducted and evaluated by comparing the conventional physics EBS system with the proposed system combining the conventional system with a measurement tool. The results and considerations will be described later.

5.2 *Method*

To confirm the effectiveness of the proposed system, a system which visualizes only the behavior of the object was used for comparison. Participants were seven university students who had taken physics courses related to engineering. Although this study focused on physics concepts that are taught to Japanese junior high school students, it is challenging even for university students to correctly understand these concepts. Before using the system, we explained the experimental procedure and the method of solving for force using arrows to the participants.

The experimental procedures comprised a pre-test (30 minutes), independent learning using the proposed system (20 minutes), and a post-test (45 minutes). The participants were given a questionnaire at the end of the experiment. The participants were divided into two groups. During the independent learning exercise, Group A performed the measurement tool installation task while using the EBS system whereas group B used only the conventional EBS system and did not perform the measurement tool installation task. The pre-test and post-test were the same format test in 30 minutes, each asking one question about the learning support system and four questions about problems involving the stationary or moving object that the participants manipulated, scored one point per one correct answer. In the post-test, in addition to the content of the pre-test, a task to make the learner explain the content of the error based on the incorrect answer was performed in 15 minutes.

5.3 Results

Table 3 shows the mean scores of the pre-test and post-test groups at same format test. The mean pre-test score was 3.7 in group A and 3.3 in group B, and the mean post-test score was 6.7 in group A and 5.0 in group B. The scores of both Group A and Group B improved between the pre- and post-test but Group A showed a greater improvement than Group B. It was also shown that the scores of both groups similarly improved between the pre- and post-test when the problem of motion system was divided and compared; here also, Group A showed a greater improvement than Group B.

Table 3

Mean Scores for Group A and Group B

	Group A			Group B		
	pre-	post-	difference	pre-	post-	difference
Mean score	3.7	6.7	3.0	3.3	5.0	1.7
(stationary object)	3.0	4.0	1.0	2.3	2.7	0.4
(moving object)	0.7	2.7	2.0	1.0	2.3	1.3

Examples of explanations for the causes of errors that were given by participants in a post hoc test are shown in Table 4. The subjects in both groups were able to explain the error appropriately in the most test, characteristics of each explanation are shown below. Students in Group B group used the conventional EBS, referring only to force and behavior, to answer the problems, as shown in explanations (4), (5), and (6), indicating that the learning exercise using the conventional physics EBS was effective. On the other hand, the students in Group A who installed the measurement tool identified errors by referring to the mechanical concept of the measurement tool, as shown in explanations (1), (2), and (3). In Group A, 3 out of the 4 participants answered the questions while referring to the parameter of load. In contrast, 0 participants in Group B did so, suggesting that the value displayed by the measurement tool could be understood by relating the input force with the resulting behavior using the proposed method in which the measurement tool was installed. In addition, as shown in explanations (2) and (3), the participants in Group A described what happened based on trial and error, suggesting that trial and error after installing the measurement tool contributed to the nature of their explanations.

Table 4

Example Explanations for the Causes of Errors

Number	Group	Explanation
(1)	A	The object does not move but has no weight, exerting no force on the floor.
(2)	A	When the measurement tool is placed to the right of each object, the indicated parameter becomes 0.
(3)	A	The acceleration of an object increases gradually when the acceleration is measured
(4)	B	Stationary but insufficient force to push object A against object B.
(5)	B	Stationary but lacking the force to push the object as well as the force the wall would use to push back against the object.
(6)	B	The force of a body in uniform motion must be balanced.

6. Summary

As a method for improving the understanding of students learning elementary physics, a learning technique including installation of a measurement tool was proposed. Through trial and error, students attempt to correct their mistakes on their own. Experiments were conducted to verify the effectiveness of the proposed system and the results suggest that the proposed method might increase understanding in learners. In addition, by having students install the measurement tool by themselves, they were given the opportunity to find solutions through trial and error.

The findings are summarized as follows:

- It was suggested that a system in which a measurement tool is installed by the learners themselves while engaged in the learning exercise may encourage the learners to search for solutions using trial and error. This is expected to not only teach the concepts of elementary physics but also the value of trial and error.
- In the description test, students wrote descriptions of their experience with the learning system, providing explanations for the causes of their errors. There were clear differences in the descriptions depending on the system used.

Additional experiments will be conducted in the future in which learners will be given predetermined errors that they must correct by using the measurement tool.

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