Experimental Evaluation of Error-Based Simulation for Dynamics Problems in Science Class at Junior High School

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Abstract: In order to solve mechanics problems, force finding on the objects of the problem is an indispensable step. Also, this step is often difficult for beginners. Therefore, there are several researches proposed supporting method for learners in this step. Error-Based Simulation (EBS) is one of the support methods. In this research, we have experimentally evaluated EBS for a dynamics problems which an object has a velocity at a junior high school. As a result, we have confirmed that EBS is promising method to support force finding correctly.

Keywords: Error-Based Simulation, Physics, Mechanics, Force, Visualization

1. Introduction

One of the most difficult steps in solving of mechanics problem is the step of force finding on the targeting objects. Therefore, examinations and support methods for this step are important research issues in mechanics education (Clement, J. (1982), Clement, J. (1993), Tao, P.-K., & Gunstone, R., F. (1999)). For this step, learners need to correlate force with motion, but this correlation is not easy.
Error-Based Simulation (EBS) is a promising method to support a learner to correlate force with motion (Hirashima, T., Horiguchi, T., Kashihara, A. & Toyoda, J. (1998), Horiguchi, T., Imai, I., Toumoto, T., & Hirashima, T. (2014)). EBS is a mechanical behavior simulation reflecting the forces that a leaner find in a problem. If any incorrect force is included, EBS generates incorrect behavior reflecting them. By observing the incorrect behavior, it is expected that the learner correlate force with motion, also detects his/her mistake and correct it. The Effectiveness of EBS has already been confirmed at static problems. In this research, we have experimentally evaluated EBS for dynamic problems.

2. Error-Based Simulation

Error-Based Simulation (EBS) is a mechanics behavior simulation which reflects learners' error about force in a mechanics problem. EBS shows strange behavior of objects, and visualizes error as difference between wrong behavior and normal simulation. In this section, we will illustrate about EBS system.

2.1 EBS System

In this research, we implemented EBS system for dynamics problems on Android tablet. Figure 1 shows user interface of our system. Screen of the system consists of problem sentence (upper stage), some buttons (middle stage), and drawing area (bottom stage).

Drawing of force, and showing of EBS are done on drawing area. On drawing of the force, learners draw force they think acting on target objects as arrow by flicking. Then, motions of objects are simulated based on this drawing by touch for "Done" button. It is supposed that learners detect and correct own error by observation for this simulation because correct motion is known for them.

The motion simulation for learning of mechanics was tried in previous study (Tao, P.-K., & Gunstone, R., F. (1999)), but it could treat possible motion. On the other hand, EBS can accept impossible motion which based on learners' mistakes.

For example, figure 1 shows the problem about the forces act on the person who skating on the ice without friction with uniform motion. In this problem, many learners draw the force direction of motion. For that drawing, the parson is accelerated in EBS.

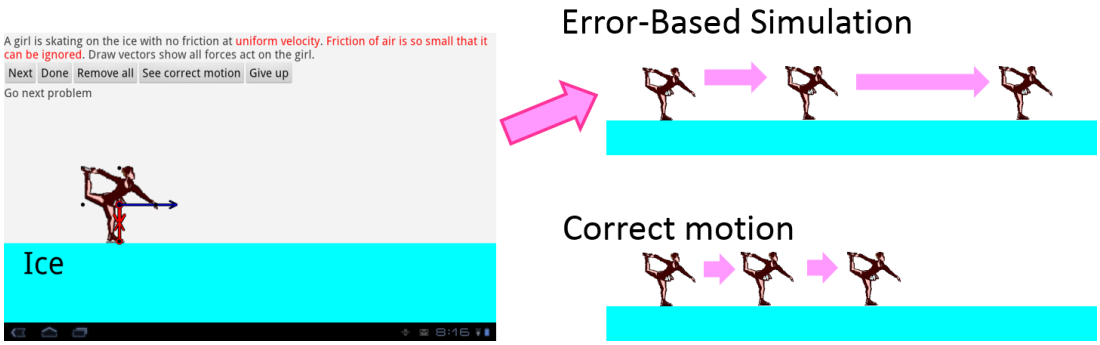

Figure 1. System Interface

2.2 Problems in this Practice

In this section, problems implemented in our system are explained. In this research, practice about dynamics problems is main target. On elementary mechanics, these three kinds of motion are treated: (1) linear uniform motion without force of motion direction, (2) linear uniform motion with balanced forces of motion direction, (3) motion with acceleration.

In this research, we implemented these three "basic problem" corresponding to above three kinds: (A) a person who skating on the ice without friction, (B) a person who dropping at constant velocity by parachute, (C) a ball thrown up vertically. Also, we implemented these three "application problem" corresponding to above three kinds: (D) a space ship moving linearly at constant velocity in cosmic space, (E) an object pushed at constant velocity on horizontal plane with friction, (F) a ball thrown up on the angle. These problems are more difficult than basic problems in that there are more forces and these motions are more complex. Also, we prepared these three problems which used in previous study (Horiguchi, T., Imai, I., Toumoto, T., & Hirashima, T. (2014)) because statics problems must have been studied before dynamics problems: (a) a block rest on horizontal plane, (b) aligned two blocks pushed toward wall, (c) piled two blocks rest on horizontal plane. From here, we call above nine problems "learned problems". These problems are shown in figure 2.

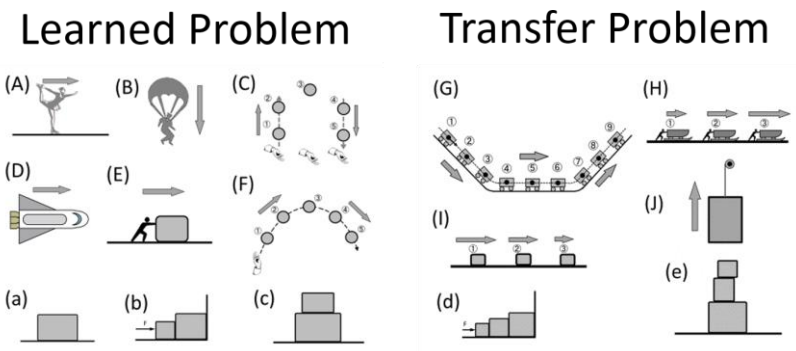

Figure 2. Used Problem

3. Practical Use

In this research, EBS system explained above was used practically. In this section, this use is explained.

3.1 Plan for Practical Use

In our research, practical use of EBS system for ninth grade was conducted to evaluate its effect. This use consists of these contents: pre-test (25min), 1st practice in same week of pre-test (static problems: 45min), 2nd practice in next week (dynamics problems: 45min), post-test in same week of 2nd practice (30min), and delayed-test after a month (30min).

3.2 Practice Method of Each Group

In this practical use, we set up three conditions and assigned a class to each group: EBS exercise group (35 students), EBS class group (33 students), Normal class group (37 students).
For EBS exercise group, we gave tablet PC each learner, and they practiced EBS system on it. While this practice at dynamics problems, basic problems (above (A) to (C)) were target to solve because students could solve about three problems in same hours at previous research (Horiguchi, T., Imai, I., Toumoto, T., & Hirashima, T. (2014)). Also, learners who solved basic problems were allowed to try application problems (above (D) to (F)). While this practice at statics problems, problem (a) to (c) were target to solve. After the practice, teacher showed only correct drawing of force.
For EBS class group, we gave tablet PC each learner, and they attended a class with EBS system. In this practice, we tried to treat problems as many as possible because this class was new initiative. As a result, we could treat all nine learned problems on EBS system.
For Normal class group, three basic dynamics problems ((A) to (C)) which shown the correct drawing at EBS exercise group, and all three statics problem ((a) to (c)) were treated to compare with EBS exercise group. In the class, learners drew the forces on the figure on the handout, and teacher explained correct drawing as if general class. After that, student drew the force again as brush up.

3.3 Evaluation Test

In this practical use, we conducted written test of force to evaluate the effect.
In pre-test, we used problem (A) to (F) and problem (a) to (c) above, and test was done for 25 minutes.
In post-test, we used nine problems on pre-test, and additional four dynamics problems and two statics problems which not used at practice. So, total fifteen problems were used at post-test for 30 minutes. Added four dynamics problems: (G) a truck moving on slope and horizontal plane without friction, (H) a sled which being pushed and accelerating on ice without friction, (I) a box decelerating on horizontal plane with friction, (J) an elevator which being lifted up at a constant speed. Added two statics problems: (d) aligned three blocks pushed toward wall (e) piled three blocks rest on horizontal plane. From here, we call above six additional problems “transfer problem” (figure 2).
Delayed-test was conducted after a month of post-test, also used problems and time are same as post-test. Result of these tests are explained at next section.

4. Results of Evaluation Test

In this section, the result and analysis for three test above are explained. In this research, we analyzed the number of correct answer (we call this number “point” from here). Also, the correct answer of problem (D) is no force, but we could not distinguish it from non-respondent. Therefore, we eliminated this problem on this analysis. From this, the maximum point was 5.

4.1 Result of Dynamics Problems

Here, the result and analysis of dynamics problems are explained. Because the exercise with EBS system is voluntarily, learners' ability may affect it. From this, we divided students along point of dynamics problems of pre-test. Learners whose point had been one or over was divided into high understanding learner and another was low understanding learner because average point was 0.543.

4.1.1 High Understanding Learner

In this time, ten learners of EBS exercise group were fallen into high understanding learners, and nine of them drew correct answer on three application problems in addition to three basic problems on EBS system. Also, 12 of EBS class group were fallen into high understanding learners, and all of them drew correct answer for all three basic problems and three application problems on EBS system. Also, 15 of Normal class group fallen into high understanding learners, and all of them drew correct answer of three basic problems in the end of class.
In learned problem, there was no significant difference between each group (Figure 3, Table 1).
In transfer problem, there was marginally significant difference just between EBS exercise group and Normal class group ($p = 0.0560 < 0.10$) at delayed-test (Figure 3, Table 2).

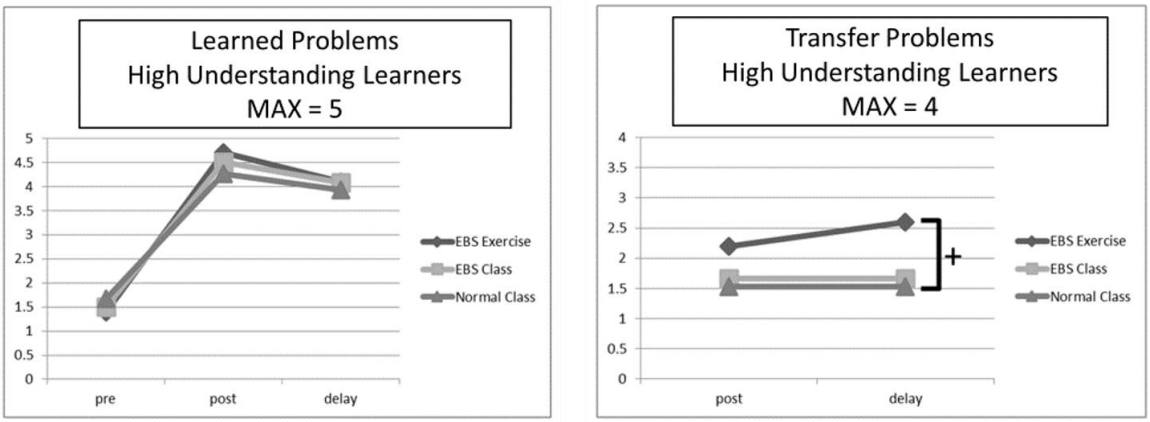

Figure 3. Result: High Understanding Learners

Table 1: Points at Test of High Understanding Learners for Learned Problems.

Learned Problems	Pre-Test	Post-Test	Delayed-Test
EBS exercise group	mean = 1.400 SD = 0.490	mean = 4.700 SD = 0.640	mean = 4.100 SD = 1.446
EBS class group	mean = 1.500 SD = 0.645	mean = 4.500 SD = 0.645	mean = 4.083 SD = 0.862
Normal class group	mean = 1.667 SD = 1.193	mean = 4.267 SD = 0.929	mean = 3.933 SD = 1.236

Table 2: Points at Test of High Understanding Learners for Transfer Problems.

Transfer Problems	Post-Test	Delayed-Test
EBS exercise group	mean 2.200 SD = 1.166	mean = 2.600 SD = 1.497
EBS class group	mean = 1.667 SD = 1.374	mean = 1.667 SD = 1.312
Normal class group	mean = 1.533 SD = 1.147	mean = 1.533 SD = 1.258

4.1.2 Low Understanding Group

In this time, 25 learners of EBS exercise group were fallen into low understanding learners, and 20 of them drew correct answer on three application problems in addition to three basic three problems on

EBS system. Also, 21 of EBS class group were fallen into low understanding learners, and 20 of them drew correct answer on three basic problems and three application problems on EBS system. Also, 22 of Normal class group are fallen into low understanding learners, and all of them drew correct answer of three basic problems in the end of class.
In learning problems, there was significant difference between Normal class group and EBS exercise group ($p = 0.0000276 < 0.05$), also between EBS class group and EBS exercise group ($p = 0.00344 < 0.05$) at delayed test at delayed-test (Figure 4, Table 3).
In transfer problem, there was significant difference just between EBS class group and EBS exercise group ($p = 0.0483 < 0.05$) at delayed-test (Figure 4, Table 4).

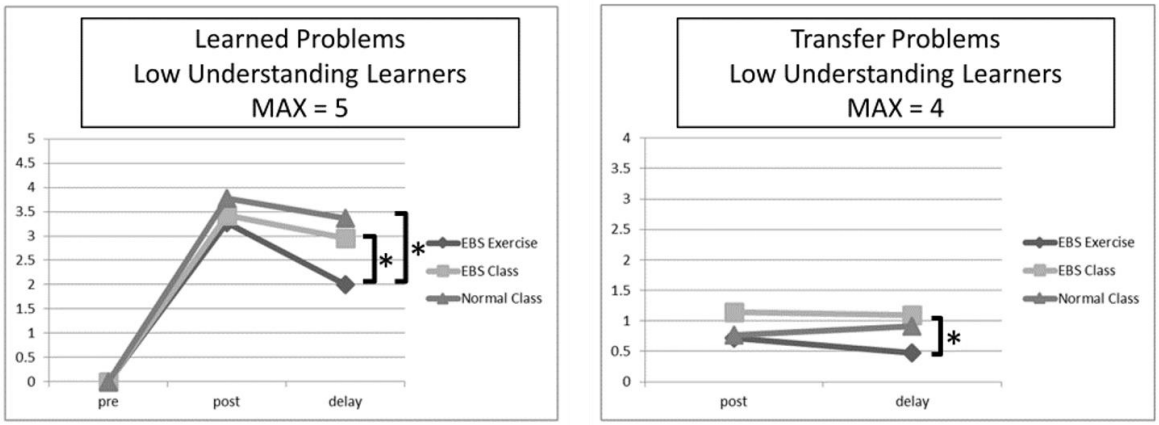

Figure 4. Result: Low Understanding Learners, Learned Problems

Table 3: Points at Test of Low Understanding Learners for Learned Problems.

Learned Problems	Pre-Test	Post-Test	Delayed-Test
EBS exercise group	mean = 0.000 SD = 0.000	mean = 3.280 SD = 1.217	mean = 2.000 SD = 1.549
EBS class group	mean = 0.000 SD = 0.000	mean = 3.429 SD = 1.466	mean = 2.952 SD = 1.618
Normal class group	mean = 0.000 SD = 0.000	mean = 3.773 SD = 0.794	mean = 3.364 SD = 0.932

Table 2: Points at Test of Low Understanding Learners for Transfer Problems.

Transfer Problems	Post-Test	Delayed-Test
EBS exercise group	mean = 0.720 SD = 0.960	mean = 0.480 SD = 0.806
EBS class group	mean = 1.143 SD = 1.166	mean = 1.095 SD = 1.231
Normal class group	mean = 0.773 SD = 0.794	mean = 0.909 SD = 1.124

4.1.3 Consideration

In high understanding learner, there was no difference between each group in learned problem in this practical use. That was indicated that students of EBS exercise group understood at the same level as other two groups in spite of exercise only with EBS system. In transfer problem, there was significant difference between EBS exercise group and Normal class group at delayed-test.
In low understanding learners, there was no significant difference between each group in post-test, but point of EBS exercise group was lower significantly than others at delayed-test in learned problem. Also, in transfer problem, the point of EBS class was higher significantly than EBS exercise group at delayed-test. These results are different from high understanding learners' one.

It is needed for EBS exercise to detect and correct own errors based on feedback from EBS system because the system does not show the answer directly. Briefly, it can be said that EBS exercise encourages "Self-regulated Learning" (Schunk, D., H., & Zimmerman, B., J. (1998), Zimmerman, B., J., & Schunk, D., H. (2001)) that need to think about own answer, which is effective but demands high capacity for learners. This can be calculated as the reason of the result of this use.
From these results, it was indicated that EBS has positive effect on high understanding learners, also has negative effect on low understanding student than normal practice. Also, it was indicated that the negative effect can be cleared by blending of EBS and normal class, but this blending can clear positive effect too. From these indications, blending of EBS and normal class is important question.

4.2 Result at Static Problems

In this practical use, we conducted practice of statics problems before dynamics one. On it, the trend of result similar to dynamics problems' one was seen. From this result, practice with EBS system only can achieve positive effect, but also can achieve negative effect, same as case of dynamics problems.

5. Conclusions

In this research, we are trying to evaluate the effectiveness of EBS system which has been used in statics problems in dynamics problems. In this paper, we reported about the design of EBS system for dynamics problems, and about its practical use.
In this practical use, it was confirmed that EBS exercise is effective for the learners with high understanding, but it is not appropriate for low understanding learners. For these low understanding learners, the method that use EBS as educational material in class was effective, but this method was as effective as normal class for learners with high understanding. From these result, it was indicated that if the learners correlate force with another element of motion is depending on prior understanding.
As future work, support for learner who don't get effect from EBS enough like seen in this use. As one of concrete methods, using of additional feedback to encourage understanding with EBS can be thought. Also, examination the types of learner who get effect from EBS by more large scale experiment. As more developmental agenda, learning support that focuses on Motion Implies Force (MIF) misconception (Clement, J. (1982)) on dynamics problem is important.

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