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Error-based Simulation in Dynamics and Its Evaluation in Junior High School

Takahito TOMOTO[a*], Isao IMAI[b], Tomoya HORIGUCHI[c] & Tsukasa HIRASHIMA[d]
[a]*Faculty of Engineering, Tokyo University of Science, Japan*
[b]*Shinjuku Junior High School, Japan*
[c]*Faculty of Maritime Sciences, Kobe University, Japan*
[d]*Department of Information Engineering, Hiroshima University*
*tomoto@ms.kagu.tus.ac.jp

Abstract: This paper reports on the practical use of Error-based Simulation (EBS) for learning dynamics in a junior high school. EBS is simulation generated from learners' erroneous answers. Differences between simulations showing correct phenomena and EBS showing unusual phenomena promote learner awareness of errors. Previously, we implemented EBS for learning about normal reaction forces in statics problems, and confirmed that EBS was effective for learners' self-correction of errors. In that problem, however, visualization of errors is easy because a correct simulation is always motionless. In this research, we implemented EBS for a dynamics problem, and put it into practical use in a junior high school. Because errors can be visualized as unexpected motion, this is an important generalization of EBS. The learning effect of EBS in dynamics problems was evaluated by comparing the results of pre-tests, post-tests, and delayed post-tests between two classes, a experimental class where students learned with the EBS and a control class where students learned as usual. The results suggest that EBS is also useful in dynamics problems.

Keywords: Learning from Errors, Learning Physics, Practical Use

Introduction

When teachers give correct answers, learners often accept them without deep understanding [1, 6]. Errors present important opportunities for deeper understanding [7], but learner awareness of errors is indispensable for effective use of the opportunity.

There are several examples of Simulation-based Learning Environments (SLEs) that simulate correct phenomena based on correct scientific concepts [8, 9]. In SLEs, learners become aware of prediction errors through trial and error. Learners, however, sometimes apply incorrect scientific concepts to explain correct phenomena. Our Error-based Simulation (EBS) is a behavior simulation generated from learners' erroneous concepts [2, 5], which usually results in unexpected phenomena. Differences between the correct phenomenon and the unexpected one promote awareness of erroneous concepts. Previously, we implemented EBS for learning about normal reaction forces in statics problems, and found that the EBS was effective [4]. In such problems, however, visualization of errors is easy because correct phenomena are always motionless. Here, we implemented EBS for dynamics problems, and put it to practical use in a junior high school. Because errors are visualized as unexpected motion, this is an important generalization of EBS.

1. Error-based Simulation (EBS)

Figure 1 shows the general framework of EBS. Learners sometimes give erroneous answers, despite knowing the expected phenomenon. EBS generates unexpected phenomena based on student errors. The difference between the expected correct phenomenon and the unexpected unusual phenomenon in visualization raises learners' awareness of their errors, and provides motivation to correct errors.

Along with reliability and suggestiveness, visibility is an important factor in effective use of EBS [4]. Visibility is the difference between the correct and the incorrect phenomenon, and affects whether learners easily become aware of errors. In terms of visibility, a qualitative difference of an object's velocity (e.g., positive, zero, or negative) is better than a proportional difference of the velocity change (e.g., increasing, steady, or decreasing") [3].

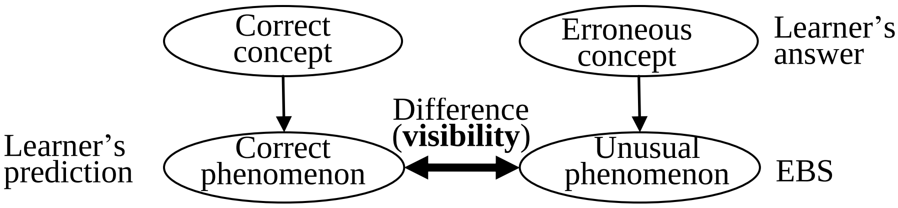


Figure 1. Framework of Error-based Simulation

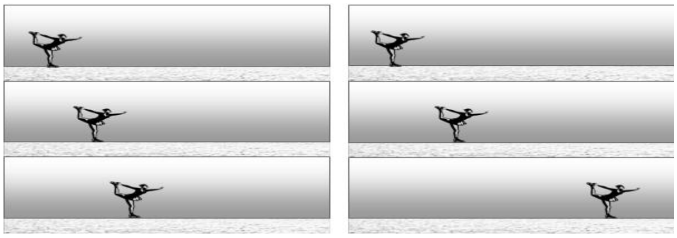
Figure 2 shows an example problem from statics. Learners are required to draw all forces acting on the displayed block. For example, if a learner believes that there are no normal reaction forces, only an arrow representing the force of gravity would be drawn. In this case, based on the learner's error, EBS generates the unexpected phenomenon that the block sinks into the ground.

(a) Learner's error (b) Resulting unusual phenomenon

Figure 2. Example error and resulting phenomenon in a statics problem

Figure 3 shows a problem that requires learners to draw arrows of force in a dynamics problem. Figure 3(a) shows linear uniform motion. Though only gravity and the normal reaction force are acting on the skater, learners often additionally draw a forward force. When this error is made, EBS generates the unexpected phenomenon that the skater moves with positive acceleration, as in the right side of Figure 3(b), though the skater should keep moving forward with constant velocity, as in the left side of Figure 3(b),.

Experimental evaluation has shown that EBS has a high learning effect for statics problems in a junior high school. This paper evaluates the practical application of EBS for dynamics problems in a junior high school. In statics problems, block velocities are zero in a correct phenomenon, so learners are made aware of errors if the velocity is positive or negative. In dynamics problems, however, simple qualitative differences in object velocities are insufficient for determining errors—observation of qualitative differences in the ratio of change in velocity is also required. This is an important generalization of EBS.



Left: Correct phenomenon

Right: Unusual phenomenon

(a) Learner's error (b) Resulting unusual phenomenon

Figure 3. Example error and resulting phenomenon in a dynamics problem

2. Practical Use and Evaluation

2.1 Evaluation Procedure

Here we consider an "EBS class" and students learning as usual in a "control class". Previously, for statics problems, students in the EBS class got statistically significant higher scores than the control class in a post-test and a delayed post-test performed three months after the post-test. The main purpose of this paper is to confirm that EBS is also useful for dynamics. To confirm this, we compared test scores of the EBS class with the control class in a pre-test, post-test, and delayed post-test.

Three classes of third-year junior high students participated in this experiment. Two classes (64 students) studied dynamics by using EBS and one class (29 students) studied it as usual. The total learning time for each class was two class periods (90 min total). All classes had already learned static mechanics. In the EBS class, each student used a computer. All classes were taught by the same teacher, who was in charge of science subjects for the students. In the EBS class, the teacher helped the students with use of the EBS system, but did not give support related to the problem solutions. In the control class, the teacher taught motion with constant acceleration, and then taught linear uniform motion with several examples and graphs showing the relationship between velocity and time.

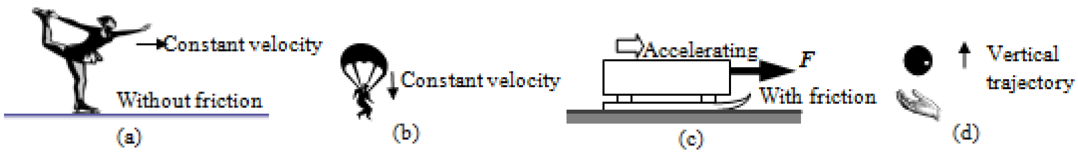


Figure 4. Learning tasks

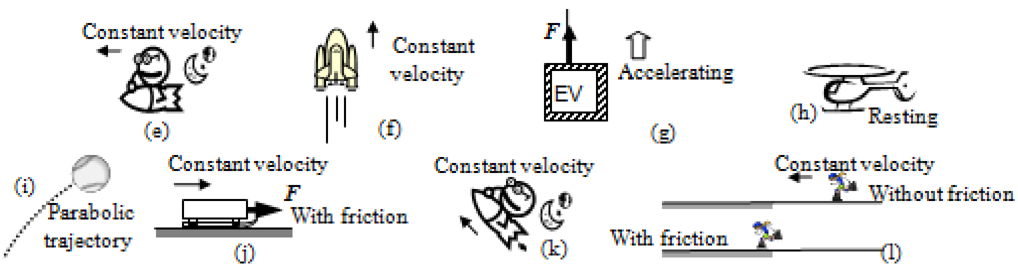


Figure 5. Evaluation tasks

The pre-test was composed of the 4 problems shown in Figure 4, which we call "learning tasks." All students learned these problems. The post-test was composed of 12 problems consisting of all problems in the pre-test and 8 new problems, which we call “evaluation tasks” (Figure 5). The delayed post-test, which was carried out three months after the post-test, contained the same problems as the post-test. The main purpose of the learning tasks was to evaluate improvement and retention of student knowledge. The main purpose of the evaluation tasks was to evaluate transfer of learning.

We categorized the 12 problems into the following three groups, according to initial velocity and the relation between the directions of total force and motion.

- Easy problems: (I) Motionless: No forces. (II) Motionless: Balanced forces [Problem (h)]. (III) Accelerated Motion: Motion and total force in the same direction. [Problems (c) and (g)]
- Intermediate problems: (IV) Linear Uniform Motion: No forces [Problems (a), (e), and (k)]. (V) Linear Uniform Motion: Balanced forces [Problems (b), (f), and (j)].
- Difficult problems: (VI) Accelerated Motion: Motion and total force in different directions [Problems (d), (i), and (j)].

Factors I and II appear in statics problems. Factor III is a naturally understandable factor where an object is accelerating in the same direction as its velocity. Problems including Factors IV or V are more difficult than those including Factors I, II, or III. Factor VI is the most difficult, because the direction of motion and the total force are different and therefore often not intuitive for learners.

2.2 Results and Discussion

The test results are shown in Figure 6, Figure 7, and Table 1. When evaluating the tests, 1 point was given for each correct force and 1 point was reduced for each incorrect force. The maximum score for the learning tasks was 10 points, and the maximum scores for the easy, normal, and difficult evaluation tasks were 5, 9, and 6 points, respectively.

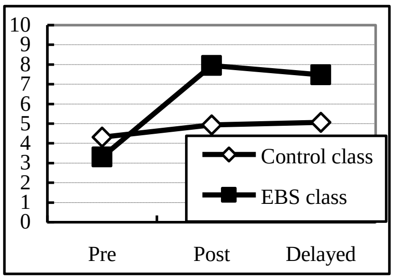
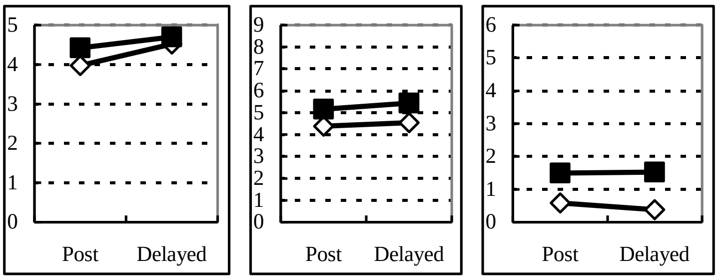


Figure 6. Learning tasks



(a) Easy (b) Normal (c) Difficult

Figure 7. Evaluation tasks

Table 1. Average test scores (and SD)

	Learning tasks (max: 10)			Evaluation tasks					
				Easy (max: 5)		Normal (max: 9)		Difficult (max: 6)	
	Pre	Post	Delayed	Post	Delayed	Post	Delayed	Post	Delayed
EBS	3.3 (2.0)	7.9 (1.7)	7.5 (1.9)	4.4 (1.1)	4.7 (0.8)	5.2 (2.2)	5.4 (2.2)	1.5 (1.4)	1.5 (1.8)
Control	4.3 (2.0)	4.9 (2.1)	5.1 (2.3)	4.0 (1.3)	4.5 (1.2)	4.4 (2.7)	4.6 (1.2)	0.59 (0.85)	0.38 (0.89)

For the learning tasks, we ran an analysis of variance (ANOVA) with Class (EBS class (a1), control class (a2)) as a between-subject factor A, and Timing (pre-test (b1), post-test (b2), delayed post-test (b3)) as a within-subject factor B.

ANOVA results for the learning tasks indicate that all main effects and an interaction were significant, with $p < .001$. The simple main effects within this interaction indicated that the effect of Class was significant for all Timing ($p < .05$), and the effect of Timing was significant for only the EBS class. In addition, multiple comparisons for Timing in the EBS class by Ryan's method indicated significant differences between post-test and pre-test/delayed post-test pairs ($p < .001$), but no significant differences between post-test and delayed post-test pairs. As for learning tasks, scores in the EBS class were higher than the scores in the control class for the post-test and delayed post-test, even though pre-test scores in the EBS class were lower than those in the control class.

For the evaluation tasks, we ran an analysis of variance (ANOVA) with Class (EBS class, control class) as a between-subject factor A, Timing (post-test, delayed post-test) as a within-subject factor B, and Difficulty (easy, normal, difficult) as a within-subject factor C.

ANOVA results for the evaluation tasks indicated that main effects of Class and Difficulty were significant($p < .001$), and one of Timing was not significant ($p > .1$), indicating that the EBS class scores were higher than the control class scores, independent of Timing and Difficulty. These results suggest that EBS in dynamics was also useful in the evaluation tasks.

Finally, we investigated the effect sizes of the evaluation using Cohen's d. In the post-test, the effect sizes of Easy, Normal, and Difficult were 0.37, 0.31, and 0.77, respectively. In the delayed post-test of the evaluation tasks, the effect sizes of easy, normal, and difficult were 0.18, 0.41, and 0.79, respectively. Although there were no statistical important differences in the timing and difficulty, EBS might be more effective when the task is more difficult and the timing is delayed.

3. Concluding Remarks

Previously, EBS was found useful for studying statics; here, we evaluated EBS in practical use for dynamics in a junior high school. Results indicate that students who learned with EBS earned higher scores than did students who learned in the usual way for learning tasks and evaluation tasks. These results suggest that EBS is useful for improving student learning in dynamics.

Acknowledgements

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