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Effects of Error-Based Simulation as a Counterexample for Correcting MIF Misconception

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Abstract. MIF (Motion Implies a Force) misconception is commonly observed in elementary mechanics learning where students think some force is applied to moving objects. This paper reports a practical use of Error-based Simulation (EBS) for correcting students' MIF misconceptions in a junior high school and a technical college. EBS is a method to generate a phenomenon by using students' erroneous idea (e.g., if a student thinks forward force applied to a skater traveling straight on ice at a constant velocity, EBS shows the skater accelerates). Such a phenomenon is supposed to work as a counterexample to students' misconception. In the practice, students first worked on pre-test of five problems (called 'learning task'), in each of which they drew all the forces applied to objects in a mechanical situation. They then worked on the same problems on system where EBSs were shown based on their answer. They last worked on post-test of the previous plus four new problems (called 'transfer task'). As a result, in both schools, the numbers of MIF-answers (the erroneous answers supposed due to MIF misconception) in learning task decreased significantly between pre-test and post-test. Effect sizes of the decrease of MIF-answers were larger than that of other erroneous answers. Additionally, the percentages of MIF-answers to the whole erroneous answers in transfer task were much lower than those in learning task. These results suggest learning with EBS not only has the effect on the resolution of MIF misconception, but also promoted the correction of errors in conceptual level.

Keywords. Mechanics, MIF misconception, Error-based Simulation, Counterexample, Practical use

1 Introduction

One of the most important purposes of elementary science education is to enable students to explain and predict natural phenomena with scientific concepts. However, students often comprehend natural phenomena with scientifically inappropriate concepts that are called misconceptions. Especially in physics, misconceptions often occur and remain even after students are taught scientific concepts [Driver, 1985; Osborne, 1985; Clement, 1982; McCloskey, 1983]. Such misconceptions are usually very hard to overcome because they are deeply rooted in students' daily experiences [Bransford, 2000; Clement, 1982; Mestre 1994]. This paper describes a method to generate counterexamples to students’ misconceptions that help students overcome the misconceptions, and presents experimental results.

Scientific experiment is a popular teaching method to make students comprehend phenomena with scientific concepts. In the teaching, first, a phenomenon is shown to students, and then, it is explained with scientific concepts that are the targets of teaching. Simulation-based learning environments (SLE) have been investigated to assist such learning from experiments and have been confirmed that they are useful for introduction or acquisition of scientific concepts [Towne 1993, Wenger 1987]. However, showing the correct phenomenon and explaining it with scientific concepts isn't always useful. Especially when students have wrong concepts for explaining correct phenomena, the misconceptions often recur [Bransford, 2000; Clement, 1982; Mestre 1994]. For example, in elementary mechanics, students often answer that gravity is the only force acting on the block on a table even after a teacher explained the concept of normal force. Most students are satisfied with the explanation that the table ’supports’ the block’s weight. That is, if misconceptions somehow ‘explain’ experiences and no shortcoming is revealed, students don’t need scientific concepts that is less familiar to them. Therefore, in order to overcome misconceptions, it is important to show students a concrete fact that reveals the shortcoming of their misconceptions and has more impact than their daily experiences. Such a fact is usually called ‘counterexample.’

Error-based simulation (EBS), which is a method to generate a phenomenon by using students’ erroneous idea, is a promising method to make such counterexample. EBS helps students be aware of errors especially when they know the correct phenomenon but comprehend it with wrong concepts [Hirashima, 1998]. For the above example, EBS generates an unnatural phenomenon where the block sinks into the table because the gravity is the only force applied to the block. The important role of EBS is to show counterexamples to students' misconceptions or erroneous answers. To show counterexamples makes students think why their idea is inappropriate and integrate the idea rooted in daily life to scientific concepts. In our previous work, we practically used EBS in junior high schools for teaching 'normal reaction' in static situations like the above example [Hirashima, 2009; Horiguchi, 2014]. The results strongly suggested that students who learned with EBS acquired deeper conceptual understanding compared to students who learned in the usual way.

In this paper, we describe a practical use and evaluation of EBS for correcting students' 'MIF (Motion Implies a Force) misconception' in dynamic situations. The practice was made in a junior high school and a technical college. MIF misconception is very commonly observed in elementary mechanics learning where students think some force is applied to moving objects. In the practice, students learned what forces were/weren't applying to moving objects in dynamical situations with EBS. For example, if students thought some force was applying to a skater traveling straight on ice at a constant velocity, the EBS was shown where the skater was accelerated. We investigated the effect of EBS by comparing the scores of pre-test (before the learning with EBS) with post-test (after the learning with EBS). In both schools, the average number of erroneous answers in post-test significantly decreased compared to that in pre-test, and the decrease of erroneous answers caused by MIF misconception was more dominant than that of other erroneous answers. This effect was observed not only in the problems students learned with EBS but also in the problems they saw for the first time in post-test. These results suggest that EBS contributed to correct students' MIF misconception at conceptual level.

In this paper, in Section 1, the framework of EBS is introduced and its feature is discussed compered with related work. The purpose of this practical use and the procedure of the experiments are described in Section 2. In Section 3, we show the results of the practice and discuss them.

2 Error-Based Simulation: A Method to Make Counterexample to Students' Misconceptions

In this section, we first introduce the framework of EBS, and then point out its feature compared to other teaching methods to correct students' misconception.

2.1 Framework of EBS

Figure 1 shows the framework of EBS. EBS is generated by mapping errors in symbolic expression to erroneous behavior. The difference in behavior expression is better to make students be aware of the errors and motivate them to correct the errors. If students have some misconception expressed in their wrong answer, the erroneous behavior they didn't predict works as a counterexample to their misconception. We have developed the simulators that generate EBS in elementary mechanics and other domains, and also developed the learning environments in which EBSs are managed from several educational viewpoints [Hirashima 1998; Horiguchi, 2006, 2012; Matsuda, 2003; Kunichika, 2006].

We introduce an example of EBS by using mechanics problems shown in Figure 2 used in this practice. A student is shown a mechanical situation and is required to draw all the forces acting on the objects in the situation. The students may make an erroneous drawing because of some misconceptions, which are regarded as the externalization of their erroneous idea. Based on the drawing, the acceleration of each object is calculated and the motion of them is simulated. In the problem of Figure 2 (a skater traveling straight on (frictionless) ice at a constant velocity), for example, students often draw the force in the direction of travel. In EBS, the skater accelerates in the direction. It is expected that such unnatural phenomenon is useful as a counterexample to students' erroneous ideas and it contributes to correction of the errors with high and intrinsic motivation.

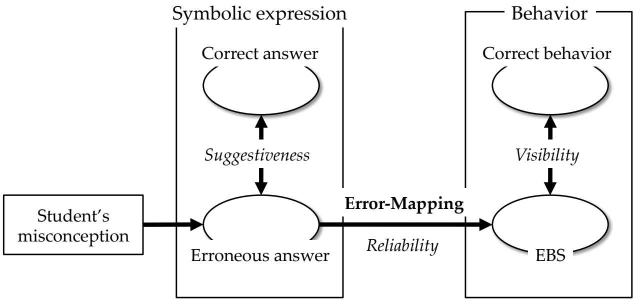


Fig. 1. Framework of Error-based Simulation

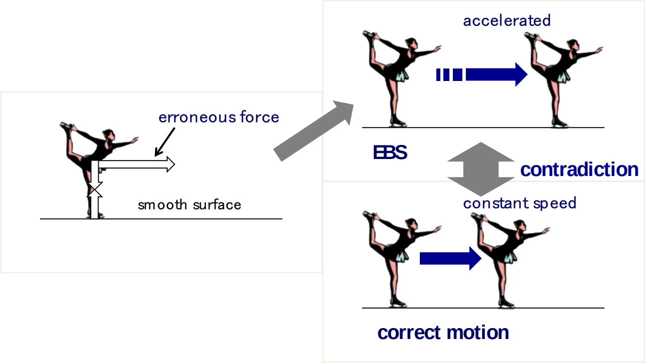


Fig. 2. An example of EBS

2.2 Related Work

For changing students' strong misconceptions, several teaching methods have been proposed. For example, Clement proposed using 'bridging analogies' [Clement, 1993] in which the gap between students' correct belief and their misconception is bridged by some intermediate analogous situations. That is, suppose students misunderstand the situation of a book on a table, which is called the 'target.' First, a situation is introduced in which a hand is pushing down a spring on a table. Most students understand the spring pushes back up against the hand. This is called the 'anchor.' Then, another situation is introduced in which a book is on a flexible board on a table. Students can understand the board pushes up the book because this situation is similar to that of the anchor. Additionally, this situation is similar to that of the target. Therefore, students can connect the anchor to the target, to understand that a 'normal force' is applied to the book from the table. It was reported that using bridging analogies in class effectively activated students' discussion and scientific thinking, through which they understand the concept normal force [Clement, 1993].

For another example, Elby designed 'epistemology-focused instruction' [Elby, 2001] in which students' conceptual development is integrated with their epistemological development. That is, suppose students misunderstand the situation of a running car at a constant velocity. Most students first think the force applied to the car in the direction of motion is greater than that by air resistance in the reverse direction. Then the teacher assists students to think about the acceleration of the car, and to connect their idea to Newton's second law. If students' first idea was correct, the car would have positive net-force, therefore it couldn't run at a constant velocity because its acceleration must be positive according to the formula 'F = ma.' In this case, students' intuition contradicts scientific concepts. After that, the teacher introduces another situation of a shoved dolly on a floor that starts to move. In this case, most students think the dolly gets accelerated because the shoving force is greater than the friction from the floor, and their intuition doesn't contradicts Newton's second law. Through such instruction, students reflected when their intuition was correct/wrong and consistent/inconsistent with scientific concepts, and could integrate the intuition with scientific concepts [Elby, 2001].

The common point between these teaching methods is to integrate students' intuition based on their daily life with scientific concepts, not to merely deny the misconception. Especially, making counterexample to the misconceptions plays an important role.

Making counterexample, which is to show students the fact that can't be explained based on their idea, is known as a useful method to correct misconceptions. It can be a trigger of 'cognitive conflict' which often cause students' conceptual change [Osborne, 1985; Glynn, 1991; Gagne, 1985; Nakajima, 1997; Fujii, 1997]. Additionally, less students who learned with counterexamples recur misconceptions than those who learned with the explanation of correct concepts [Bransford, 2000].

However, counterexamples should be carefully made and shown because students often ignore them or need help to comprehend them to reach correct understanding [Chinn, 1993; Fukuoka, 94; Nakajima, 97]. That is, counterexamples should be accepted by students as something important, and some help should be given to lead them to correct understanding [Fukuoka, 94; Nakajima, 97]. Though the teaching methods described above appropriately utilize counterexamples in view of these points, they have a common problem. That is, in these methods, a set of situations must be prepared beforehand in each of which students' idea goes well or doesn't go well. For example, in using bridging analogies, an appropriate situation should be found that is similar to both the target and the anchor. In epistemology-focused instruction, such situations should be carefully designed and sequenced based on the scenario of instruction. This is a very difficult task even for human teachers.

The advantage of EBS compared with these methods is that no other situation is necessary to make counterexamples. If students have a wrong idea, EBS is directly generated based on their answer. (Note that students' answer should be the expression of the wrong idea and include sufficient information to generate simulation.) Additionally, even when students predict the correct phenomenon but explain it with wrong concepts, EBS can be a useful counterexample. (When students think no force except gravity, a book sinks into a table. When they think a car's net-force is positive, it accelerates instead of keeping a constant velocity) Furthermore, since the simulator for EBS (called 'robust simulator') explicitly handles the constraints of the model for generating simulation, it understands what constraint is violated [Horiguchi, 2006;

Horiguchi, 2012]. (The constraints 'two solid objects never overlap' and 'the car keeps a constant velocity' are violated in the above examples, respectively.) Therefore, it becomes possible to define the criteria for estimating the 'surprisingness' of EBSs as counterexamples.

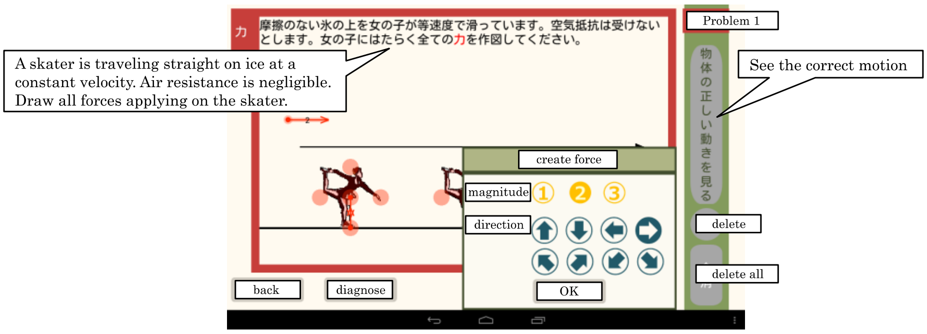
3 Experiment

3.1 Purpose

In this research, we investigated the usefulness of EBS to correct students' MIF misconception. MIF (Motion Implies a Force) misconception is very commonly observed in elementary mechanics class where students think some force is applying to moving objects. According to [Clement, 1982], we classified MIF misconception as follows. MIF-(1): Force in the direction of motion is necessary to cause and keep objects' motion even when they move at a constant velocity, MIF-(2): Especially when there is explicit resistance against motion, force that is greater than the resistance is necessary to keep the motion, and MIF-(3): The force in the direction of motion increases/decreases according to the velocity of the motion. When students' wrong answer can be explained based on these misconceptions, we call it 'MIF-answer.' If the number of students' MIF-answers decreases after the learning, it is supposed that their MIF-misconception was resolved through the learning.

3.2 Instruments

Learning Environment In this research, an EBS-based learning environment (hereafter, called ‘the system’) was implemented as an Android tablet-PC application, in which students worked on a set of problems in mechanics. Figure 3 is a snapshot of the system. In each problem, students were given a figure of mechanical situation and required to draw all the forces acting on the objects in the situation as arrows (After choosing the magnitude and direction of force from a menu, students tapped ‘create’ button to make such an arrow appear on the screen. They then dragged it onto an object to apply.). As for each object, the net-force was calculated based on the drawing, then the motion was simulated by using Newton’s second law. When the drawing included errors, the motion of objects often became unnatural against students' prediction. Such simulation was expected to work as a counterexample to students' solution, therefore students would get aware of the errors and correct them.



摩擦のない氷の上を女の子が等速度で滑っています。空気抵抗は受けないとします。女の子にはたらく全ての力を作図してください。

A skater is traveling straight on ice at a constant velocity. Air resistance is negligible. Draw all forces applying on the skater.

Fig. 3. A snapshot of the system

Tests In the experiment, the MIF misconceptions (1), (2) and (3) described in the previous section were targeted. If students' idea reflected these misconceptions before using EBS and didn’t after using EBS, their MIF misconceptions were supposed to be resolved. We implemented the following five problems on the system:

Problem-(a): A skater traveling straight on (frictionless) ice at a constant velocity (in which MIF-(1) is predicted. Students are likely to draw the force in the direction of travel. In EBS, the skater accelerates in the direction.)

Problem-(b): A man who is descending in the air with a parachute at a constant velocity (in which MIF-(2) is predicted. Students are likely to draw the downward and upward forces the former of which is greater than the latter. In EBS, the man accelerates downward (in the direction of motion).)

Problem-(c): A thrown ball rising vertically upward. (in which, MIF-(3) is predicted. Students are likely to draw the upward force which decreases as the ball ascends. In EBS, the ball accelerates upward (in the direction of motion).)

Problem-(d): An object on a floor shoved horizontally with friction at a constant velocity (in which MIF-(2) is predicted)

Problem-(e): A thrown ball rising in an oblique direction against the horizon (in which MIF-(3) is predicted)

These five problems were called the ‘learning task.’ Problem-(a), (b) and (c) were used as the ‘basic problems.’ Problem-(d) and (e) were used as the advanced problems of problem-(b) and (c) respectively. Additionally, we predicted MIF-(1) could appear in all the problems. For example, in problem-(b), students could draw only the downward force. In such a case, it was counted as MIF-(1).

In the pre-test, students solved the five problems of learning task (which they would learn on the system) as a written test. In the post-test, in addition to the five problems, they solved the following four problems of ‘transfer task’ as a written test.

Problem-(f): A dolly first descends a slope and then comes to a horizontal floor. There is no friction throughout the motion.

Problem-(g): A sled is accelerating on (frictionless) ice with continuous horizontally force.

Problem-(h): A box is decelerating on a horizontal floor with friction.

Problem-(i): An elevator is being lifted up at a constant velocity.

Subjects and Procedure We practically used our system for teaching mechanics in a junior high school and a technical college. In a junior high school, thirty-five third grade students participated in the class. In a technical college, thirty-two third grade students participated in the class. In both schools, subjects first worked on the pre-test, then worked on the learning task with the system. After that, they worked on the post-test.

4 Results and Discussion

We scored the answers of the subjects in pre-test and post-test as follows. If there was an erroneous arrow that was supposed due to MIF misconception in a drawing, the answer was classified as ‘MIF-answer.’ If there was erroneous arrows but none of them was supposed due to MIF misconception, the answer was classified as ‘other erroneous answer.’

4.1 Result in a junior high school

Figure 4 shows the result of learning task in pre-test and post-test. As for the learning task (five problems), the average number of erroneously answered problems was 4.6 in the pre-test, while it significantly decreased to 1.3 in the post-test (Wilcoxon signed-rank test, p=0.418×10E-6; effect size, r=0.673). The average number of MIF-answered problems was 2.9 in the pre-test, while it significantly decreased to 0.4 in the post-test (Wilcoxon signed-rank test, p=0.116×10E-5; effect size, r=0.640). The average number of other erroneously answered problems was 1.7 in the pre-test, while it significantly decreased to 0.9 in the post-test (Wilcoxon signed-rank test, p=p=0.783×10E-3; effect size, r=0.499). This result reveals MIF-answered problems decreased more dominantly than other erroneously answered problems. Additionally, the rate of MIF-answered problems to the whole erroneously answered problems was 63% in the pre-test, while it was 33% in the post-test.

Figure 6 shows the result of transfer task in post-test. As for the transfer task (four problems), the average number of MIF-answered problems was 1.2, while the average number of other erroneously answered problems was 1.6. The rate of MIF-answered problems to the whole erroneously answered problems was 42%.

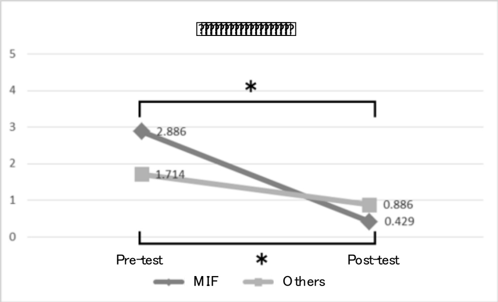


Fig. 4. Learning task in junior high school

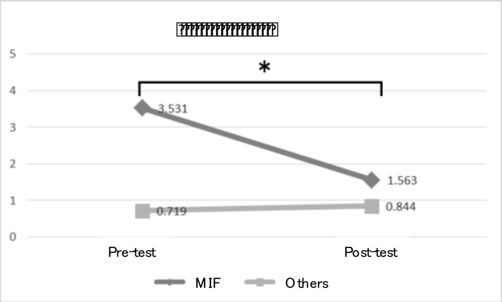


Fig. 5. Learning task in technical college

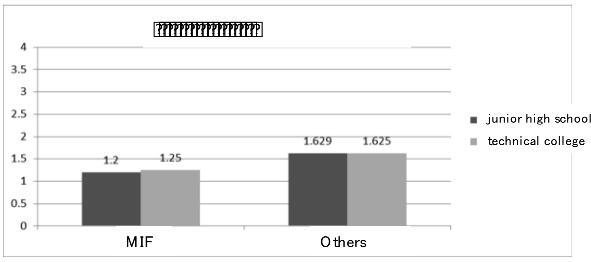


Fig. 6. Transfer task

4.2 Result in a technical college

Figure 5 shows the result of learning task in pre-test and post-test. As for the learning task (five problems), the average number of erroneously answered problems was

4.3 in the pre-test, while it significantly decreased to 2.4 in the post-test (Wilcoxon signed-rank test, p=0.343×10E-4; effect size, r=0.597). The average number of MIF-answered problems was 3.5 in the pre-test, while it significantly decreased to 1.6 in the post-test (Wilcoxon signed-rank test, p=0.880×10E-5; effect size, r=0.624). The average number of other erroneously answered problems was 0.7 in the pre-test, while it was 0.8 in the post-test (there was no significant difference between them). Additionally, the rate of MIF-answered problems to the whole erroneously answered problems was 83% in the pre-test, while it was 65% in the post-test.

Figure 6 shows the result of transfer task in post-test. As for the transfer task (four problems), the average number of MIF-answered problems was 1.3, while the average number of other erroneously answered problems was 1.6. The rate of MIF-answered problems to the whole erroneously answered problems was 43%.

4.3 Implication

As for the learning task, in both schools, the average numbers of MIF-answered problems decreased significantly between pre-test and post-test. Therefore, this result suggests learning with EBS has the effect on the resolution of MIF misconceptions, while our previous research only showed using EBS decreased the number of students' erroneous answers.

Additionally, in both schools, the effect size of decrease of MIF-answers was large (r=0.640 in junior high school; r=0.624 in technical college). Though the numbers of other erroneous answers in junior high school also decreased significantly, the effect size of decrease of them was medium (r=0.499). In technical college, the decrease of the numbers of other erroneous answers wasn't significant.

Though the problems of learning task were the same as those subjects learned with the system, this result indicates certain effect of EBS. That is, if subjects had answered in the post-test merely based on the memorized correct answers they met during learning with the system, both types of erroneous answers would decrease to the same degree, but actually there was the difference between them. This fact suggests learning with EBS triggered the correction of errors in conceptual level.

As for transfer task, on the other hand, the rate of MIF-answers to the whole erroneous answers was 42% in junior high school and 43% in technical college respectively. These percentages are much lower than those in pre-test (63% in junior high school; 83% in technical college; note that these data are of learning task). This fact suggests students who learned with EBS make less MIF-answers even in problems they first met, which means the possibility of the correction of errors in conceptual level.

The effect on the decrease of MIF-answers was observed in both junior high school and technical college students. We then consider the difference between them. Junior high school students had learned the relation between force and motion with qualitative explanation but hadn't with mathematical formalism (i.e., equations) yet. On the other hand, technical college students had already learned mechanics with mathematical formalism. The fact that technical college student made a lot of MIF-answers confirms the finding of preceding literature that learning mechanics with mathematical formalism is inefficient for resolving MIF misconception. On the other hand, the fact that technical college students made less other erroneous answers than junior high school students suggests that technical college students better understands mechanics except MIF misconception. Additionally, the decrease of MIF-answers was observed more clearly in junior high school students than technical college students. This fact suggests the possibility that learning with equations promotes the correction of non-MIF misconceptions but doesn't (or rather obstructs) the resolution of MIF misconceptions. Though the number of subjects in this experiment was not enough to derive general conclusion, we think our method is promising for clarify the relation between learning with mathematical formalism and MIF and other misconception, and the effect of EBS on them.

5 Conclusion

In this paper, we reported a practical use of Error-based Simulation (EBS) for correcting students' MIF misconceptions in a junior high school and a technical college. As a result, in both schools, it was suggested that EBS not only had the effect on the resolution of MIF misconception, but also promoted the correction of errors in conceptual level. The number of problems used in the experiment wasn't so large, but they covered most typical situations of MIF misconceptions, the resolution of which is a central issue in learning elementary mechanics. Therefore, we think this result has a certain amount of generality and usefulness.

Our future work is, first, to confirm the result with larger number of subjects. Additionally, as described above, we should investigate the effect of EBS before and after learning mechanics with mathematical formalism. It is also important to clarify how to combine EBS with other teaching methods and embed EBS in lessons in pedagogically effective way.

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