Evaluation of Error-Based Simulation by Using Qualitative Reasoning Techniques

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Abstract

This paper introduces an application case of qualitative reasoning techniques to realize Intelligent Learning Environment with Error-Based Simulation (EBS). EBS is a method to generate feedback for learning from mistakes, targeting an erroneous equation made in solving a mechanics problem. It is a behavior simulation that is generated by changing the value of "velocity" or "acceleration" of an object by using an erroneous equation. In the EBS, the object behaves in a strange manner. The difference between an EBS and normal simulation visualizes the error. Although EBS is a promising method to make a learner aware of a mistake in an equation, it isn't always effective. Therefore, evaluation and management of EBS is necessary. In this paper, the framework to evaluate EBS by using QSIM and DQ-analysis are reported.

1. Introduction

A mistake gives a good learning opportunity for a learner(Perkinson 84). To use the opportunity effectively, making the learner aware of the mistake is indispensable. Because a mistake usually appears in the learner's action, feedback for the action is necessary for the learner to notice the mistake. Therefore, a method to generate feedback for a mistake plays a crucial role in the learning. Direct indication of the error is the simplest and easiest feedback. However, this type of feedback is often ineffective in many cases, because the learner often accepts the indication passively and doesn't think of the meaning behind the error. To actually learn from mistakes, feedback that can make the learner aware of the mistake by him/herself is required. It should also be able to motivate the learner to correct the mistake. We call the environment with such feedback for mistakes "Error Awareness Environment." Our research goal is to design and develop a computer-based Error Awareness Environment.

Error-Based Simulation (EBS)(Hirashima et al. 95) is a method to generate feedback for learning from mistakes by targeting an erroneous equation made in solving a mechanics problem. It is a behavior simulation that is generated by changing the value of "velocity" or "acceleration" of an object by using an erroneous equation. In the EBS, the object behaves in a strange manner. The difference between an EBS and normal simulation visualizes the error.

Although EBS is a promising method to make a learner aware of a mistake in an equation, it isn't always effective. For example, when the difference between an EBS and normal simulation isn't clear, a learner cannot judge which behavior is correct. Such EBS is not only useless but also may confuse the learner. Therefore, evaluation and management of EBS is necessary (Hirashima et al. 98). In the evaluation, we use the following three factors: (1) visibility, (2) reliability, and (3) suggestiveness. The visibility factor is related to whether or not EBS has enough difference from the normal simulation to visualize the error. The reliability relates to whether or not the learner depends on the difference visualized by EBS. The suggestiveness is a factor related to whether or not the difference suggests the cause of the error.

The visibility is the most fundamental factor of these three. Every EBS shows the behavior reflecting error. However, EBS cannot always visualize the error. Through several experiments (Horiguchi et al. 98), we confirmed that when differences between EBS and a normal simulation weren't qualitative ones in "velocity" or "acceleration", a learner often could not judge which behavior was correct. This means that such EBS lacked enough visibility. EBS without enough visibility is not only useless but also may confuse the learner. Therefore, to evaluate the visibility is an essential factor to use EBS effectively. In this paper, an evaluation of visibility of EBS by using qualitative reasoning techniques is described. First, by using a qualitative simulation (Kuipers 94), the behavior of EBS is predicted. This behavior is compared with the behavior of a normal simulation, similarly predicted by using the qualitative simulation. Then, the parameters of which perturbation causes qualitative differences between EBS and a normal simulation are sought by using comparative analysis (Weld 90). When a qualitative difference is found in the above

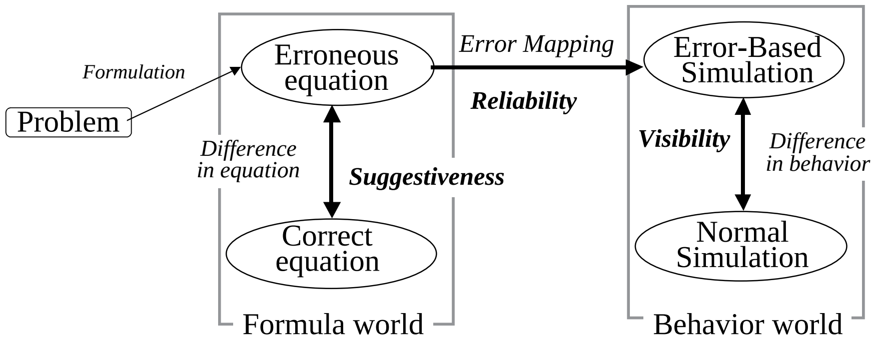

Figure 1. Framework of Error-Visualization with EBS (Error-Based Simulation).

evaluation, the EBS has sufficient visibility. Currently, a module to evaluate EBS in visibility is implemented.

In this paper, first, EBS and the three factors that are used to evaluate the EBS are introduced in Section 2. Then, the evaluation of visibility of EBS with qualitative reasoning techniques is explained in Section 3.

2. Error-Based Simulation

2.1 Framework

Figure 1 shows the framework of Error-Visualization by EBS. The EBS is generated by mapping an erroneous equation in formula-world to simulation-world. EBS shows irregular and unnatural behavior in contrast with the behavior of normal simulation. The difference makes the learner aware of the error in the equation.

The procedure to generate EBS is as follows: EBS-generator specifies the object that behaves in a strange manner reflecting the erroneous equation. The attribute "velocity" or "acceleration" is chosen in order to reflect the error to the behavior of the specified object. Then, the value of the chosen attribute is calculated based on the erroneous equation and all the other values are calculated based on the normal equation. Therefore, the error in the erroneous equation is visualized as a strange behavior of the specified object. In Figure 2, Equation-A is correct and the others are wrong. In EBS for Equation-B, the specified object is the Block, and the attribute that was calculated by using Equation-B is acceleration. So, the Block ascends the Slope in the EBS, while normal simulation shows the Block descending the Slope.

The EBS for Equation-B visualizes the error clearly. EBS, however, is not always effective. So, evaluating the effect of EBS is necessary. We propose a framework to manage EBS where the three factors, that is, (1) visibility, (2) reliability, and (3) suggestiveness are used to evaluate EBS. In the following sections, each of them is explained briefly. The methods to evaluate EBS in visibility are explained in Section 3.

2.1 Visibility

The procedure to generate EBS doesn't pay attention to what kind of difference EBS has from the normal simulation. So, EBS that isn't useful to visualize the error in an erroneous equation is often generated. In Figure 2, EBS for Equation-C only shows the Block moving in the same direction as the normal simulation along the Slope at a little different velocity and acceleration. In this case, it is difficult for the learner to judge which behavior is correct. So, for Equation-C, EBS shouldn't be used directly. However, when the angle of the Slope Ø increases, velocity and acceleration in EBS decrease while ones in a normal simulation increase. Such a strange change in behavior enables the learner to be aware of the error.

We assumed that the conditions in order for EBS to be effective for error-visualization are as follows:

(1) *Condition for error-visualization-1 (CEV-1):* There is a qualitative difference between the object's velocity in EBS and the one in normal simulation, that is, the qualitative values (e.g. "plus", "zero" and "minus") of their velocity are different. For example, in Figure 2, the qualitative values of velocity of EBS for Equation-B is "minus", while the one of normal simulation is "plus." Because the EBS satisfies the CEV-1, the EBS is judged to have enough visibility.

(2) *Condition for error-visualization-2 (CEV-2):* There is a

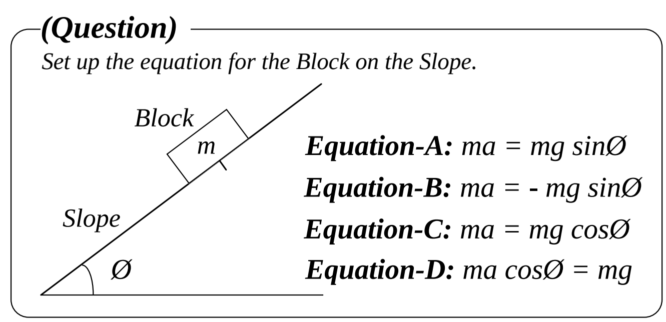

Figure 2. An Example of Mechanics Problem.

qualitative difference between the object's velocity in EBS and the one in normal simulation, that is, the qualitative values (e.g. "increasing", "steady" and "decreasing") of the ratio of their velocity's change to a parameter's change are different. For example, in Figure 2, the velocity of Block in EBS for Equation-C decreases when the Angle of the Slope increases. In contrast, the velocity of Block in normal simulation increases when the Angle of the Slope increases. Therefore, EBS for Equation-C with perturbation of Ø satisfies CEV-2. Then, the EBS is judged to have satisfactory visibility due to perturbation of Ø. Here, acceleration is considered as the change of velocity to time change. Therefore, EBS for Equation-B satisfies both of CEV-1 and CEV-2.

Here, we assumed the following preference: [CEV-1 & CEV-2] > [CEV-1] > [CEV-2]. [A] > [B] means that EBS satisfying A is better than B in visibility. When an EBS cannot satisfy any conditions of error-visualization, the EBS is judged to not have enough visibility. So the EBS is not used as feedback for the error. We have reported the verification and discussion about the conditions and the preference in (Horiguchi et al. 98; Horiguchi et al. 99).

To check CEV-1 and acceleration (CEV-2 for time), qualitative simulation is used. Then to check CEV-2, comparative analysis is used. They are explained in Section 3.

2.2 Reliability

A learner is able to be aware of the strange behavior in an EBS that has enough visibility. However, if the learner doesn't believe that the EBS reflects the erroneous equation the learner made, the EBS is not effective in making the learner aware of the error. This factor is important to manage EBS effectively. We call this factor "reliability".

For example, for Equation-C in Figure 2, "visible" EBS can also be generated by using a boundary value, in this case, Ø = 0 or Ø = 90. In the EBS with Ø = 0 (EBS-1), the Block moves with positive acceleration. Because the EBS satisfies CEV-1 and CEV-2, EBS-1 is better than the EBS with the perturbation of Ø (EBS-2) in visibility. However, in the result of a preliminary experiment in which we showed a few learners the above EBSs and asked them which EBS is more useful, some of them answered that EBS-2 is better than EBS-1. They remarked that the mechanical system in EBS-1 looks too different from the original system while the one in EBS-2 doesn't. This result suggests that modification of parameter to generate visible EBS often decreases the reliability of EBS, although the modification is useful to make EBS visible.

The reliability of EBS depends on the modification method. Currently, we have two modification methods: (1) perturbation method and (2) boundary value method. Each method is used in the range where the equations don't change. The change of the appearance with perturbation method is smaller that the change with boundary value method. So, we use the following preference: [no modification] > [perturbation] > [boundary value]. "No modification" means to use raw EBS. We have reported the verification and discussion about the preference in (Horiguchi et al. 99).

2.3 Suggestiveness

When an EBS has enough visibility and reliability, it is enough to make a learner notice the error. The visualized error motivates the learner to correct it. Here, we have to consider one more factor, that is, the suggestiveness of the EBS. Observing the EBS, the learner not only recognizes the strange behavior but also guesses the origin of the strangeness. For example, opposite acceleration against normal simulation usually suggests a missing correct force or the existence of a wrong one. When such a suggestion indicates adequate origin of the error, the learner may correct the error by him/herself. If the suggestion doesn't fit the error, it is necessary to give the learner additional guidance to correct the error. In several cases, the EBS should not be provided. Based on this consideration, we are discussing the suggestiveness of EBS and "Criteria for Cause-of-Error Visualization (CCEV)" (Horiguchi and Hirashima 00).

In this chapter, we have introduced the three factors to evaluate EBS, that is, (1) visibility, (2) reliability and (3) suggestiveness. For the visibility and the reliability, the preferences have been proposed. Because the preferences are local ones, the best EBS is not always decided. In such a case, EBS-manager has to decide which of visibility and reliability, to give priority to. To develop on EBS-manager that takes the all three of the factors into consideration is our future work.

3. Evaluation of Visibility

The EBS-manager evaluates the visibility of EBS with the following three methods. In the first method, the EBS-manager compares the qualitative behavior of the EBS with that of a normal simulation. Here, QSIM (Kuipers 94) is used to predict the qualitative behaviors. When a qualitative difference in the velocity or acceleration is found, the EBS-manager judges that EBS has enough visibility. In the second method, the EBS-manager tries to find parameters of which perturbations cause the qualitative difference that satisfies the condition of error-visualization. Here, DQ-analysis (Weld 88) is used to find such parameters. When such a parameter is found, the EBS-manager judges that the comparison of the change in behaviors caused by the change of the parameter has enough visibility. Then, in the third method, the EBS-manager compares the qualitative behavior of the EBS with that of a normal simulation under a specific value of a parameter. For example, the angle of a slope is usually in the following range: 0 < Ø < 90. Although an equation of motion of an object on a slope is valid when Ø = 0 or Ø = 90, these values are specific ones. Currently, we don't have any techniques to find such parameters and values that cause of the qualitative difference. So, the pairs of the parameter and the specific value are prepared. Then, for the physical system reflecting each of the pairs, the evaluation with QSIM is carried out.

In the following section, the first evaluation with QSIM and the second evaluation with DQ-analysis are explained.

3.1 Qualitative Simulation

First, the EBS-manager predicts qualitative behavior of the EBS by using qualitative simulation and compares it with qualitative behavior of a normal simulation similarly predicted by qualitative simulation. When a qualitative difference is found, the EBS-manager judges that the EBS is effective for error-visualization.

By using QSIM, the EBS-manager derives the sequence of qualitative states based on an erroneous equation and similarly derives the sequence of qualitative states based on a normal equation. The qualitative state (called QS) consists of "qualitative value of velocity" and "qualitative value of acceleration." The sequence of QSs is described as {QS1,..., QSn}. Let {QS1,..., QSn} be the sequence of QSs based on an erroneous equation and let {QS1',..., QSn'} be the sequence of QSs based on a normal equation. Then the EBS-manager compares both sequences and searches for the interval in which QSi has a qualitative difference from QSi' (in the sense of CEV-1). When such an interval is found, the EBS corresponding to the interval is used to visualize the error. Note that if there are several intervals in which QSi has a qualitative difference from QSi', it is necessary to judge which interval is the most effective for error-visualization. The most effective interval means the interval in which QSi has the most effective qualitative difference from QSi'.

For example, in Figure 3 (initial velocity is added to the problem in Figure 2), there are two intervals in which the EBS based on Equation-B has qualitative differences from a normal simulation based on Equation-A. In Interval-1 (I1), the EBS has a qualitative difference only in acceleration, that is, only CEV-2 is satisfied. However, in Interval-2 (I2), the EBS has qualitative differences in velocity and acceleration, that is, both CEV-1 and CEV-2 are satisfied. Therefore, the EBS-manager judges that Interval-2 is more effective for error-visualization than Interval-1. In this case, the EBS-manager is sometimes required to adjust parameters to show Interval-2. For example, in Figure 3, if the length of the Slope (x0) is too short or initial velocity (v0) is too large, the Block in the EBS doesn't behave according to the sequence of qualitative states that contains Interval-2 because the location of the Block comes to zero before the velocity of the Block comes to zero. (Transition of location occurs before the one of velocity occurs.) Therefore, the EBS-manager should adjust the parameter x0 or v0 in order for the Block in the EBS to behave according to the sequence of qualitative states that contains Interval-2. Since QSIM cannot treat such a parameter adjustment, formulation of the method of the parameter adjustment is one of the most important issues.

3.2 Comparative Analysis

The EBS-manager also tries to find parameters by using comparative analysis of which perturbation cause qualitative differences between the EBS and a normal simulation. After deriving the sequence of qualitative states based on an erroneous equation by QSIM, the EBS-manager derives the sequence of qualitative directions corresponding to the sequence of qualitative states with perturbation of a parameter by using DQ analysis (Weld 88). It similarly derives the sequence of qualitative directions with a perturbation of the same parameter based on a normal equation. For one qualitative state, two types of qualitative directions are derived, one is "qualitative value of the ratio of velocity's change to a parameter's (except time) change" and the other is "qualitative value of the ratio of acceleration's change to a parameter's (except time) change."

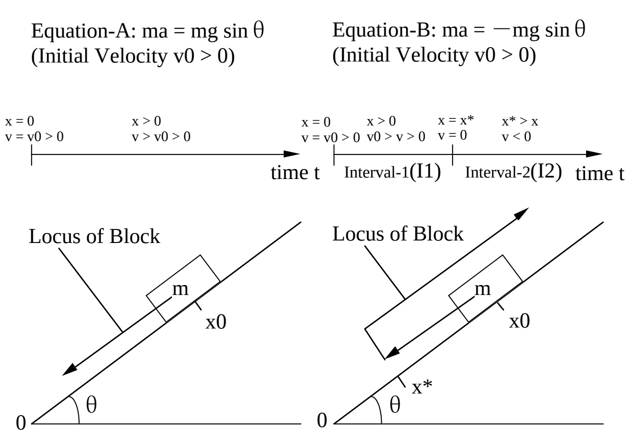

Figure 3. The Intervals in Which EBS has Qualitative Differences from a Normal Simulation.

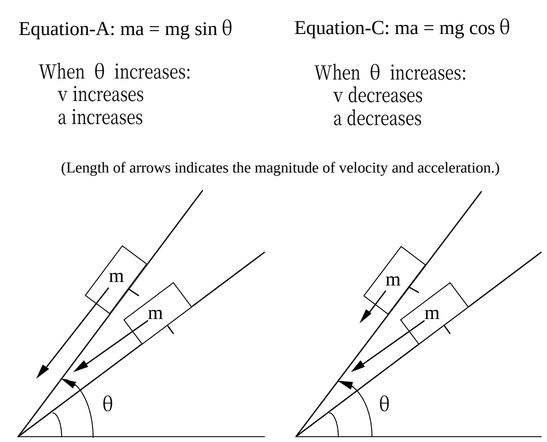

Figure 4. An Example of the Parameter of Which Perturbation Causes a Qualitative Difference.

The pair of them for QS is called QD. The sequence of QDs is described as {QD1,..., QDn}. Let {QD1,..., QDn} be the sequence of QDs based on an erroneous equation and let {QD1',..., QDn'} be the sequence of QDs based on a normal equation. Then the EBS-manager compares both sequences and searches for the interval in which QDi has a qualitative difference from QDi' (in the sense of CEV-2). When such an interval cannot be found with a perturbation of a parameter, the EBS-manager runs the same process with the perturbation of another parameter. When such a parameter and interval are found, the EBS corresponding to the parameter and interval is used to visualize the error.

For example, in Figure 4 (the same problem as Figure 2), for Equation-C, the EBS-manager cannot find any qualitative difference between the EBS based on Equation-C and a normal simulation based on Equation-A by qualitative simulation. In this case, by using comparative analysis, Ø is found as a parameter of which perturbation causes qualitative difference between the EBS based on Equation-C and a normal simulation based on Equation-A. Increasing Ø increases acceleration of the Block in the normal simulation, while increasing Ø decreases acceleration of the Block in the EBS.

4. RELATED WORKS

Most Interactive Simulation Environments (ISE) for education have the ability to visualize a learner's error. The framework of ISE, however, is different from EBS. In this section, we classify the existing ISEs and illustrate the position of EBS.

Simulation is able to provide a behavior which is different from a learner's erroneous idea or prediction. Then, such behavior is often useful to make the learner to be aware of her/his error (Osborne and Freyberg 1985; Glynn, Yeany and Britton 1991). From this viewpoint, most ISEs can be divided into the following two categories:

The first is illustrated in Figure 5. In this framework, it is assumed that when a learner has an erroneous idea, the learner predicts an erroneous behavior reflecting that idea. Based on this assumption, showing the correct behavior is useful. When a learner thinks the difference is important between the correct behavior and the erroneous predicted one, the learner is able to be aware of the error. We call this method "Correct-Mapping." Several learning environments in physics use this method [Murray et al. 1990; White 1993].

The second is illustrated in Figure 6. A learner doesn't always predict an erroneous behavior when the learner has an erroneous idea. The learner often knows a correct behavior in spite of her/his erroneous idea. For example, in Dynaturtle [DiSessa 1982], a learner operates "turtle" and tries to move it following her/his prediction. When a learner has an erroneous idea, the learner fails to control it. The difference between the correct behavior predicted by her/him and the one generated by erroneous operation often makes the error visible. We call this method "Error-Mapping." Several training environments use this method.

Most ISEs using the second method, however, only deal with errors of parameters. All phenomena generated in the environments follow correct rules. When a learner puts errone-

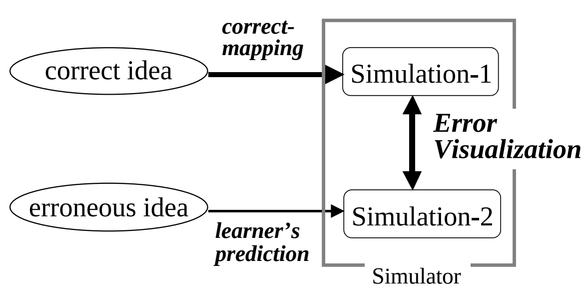

Figure 5. Correct-Mapping.

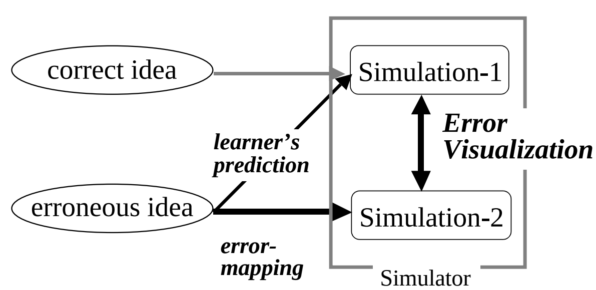

Figure 6. Error-Mapping.

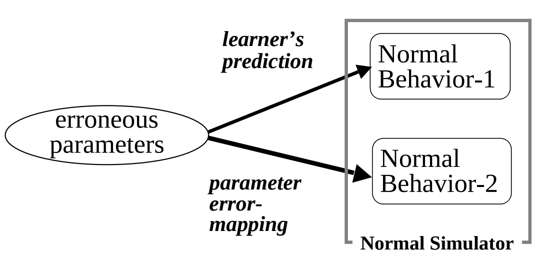

Figure 7. Parameter-Error-Mapping.

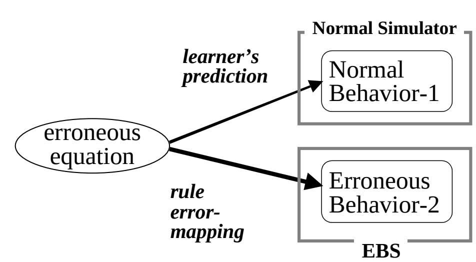

Figure 8. Rule-Error-Mapping.

ous parameters into a simulator, the learner is usually presented with unexpected behavior. Although the behavior is different from her/his expectation, it is correct for the inputted parameters. Therefore, only one normal simulator is required in such ISEs. We call this type of error-mapping "Parameter-Error-Mapping." The framework is illustrated in Figure 7.

However, there are not a few learners who formulate erroneous equations in solving mechanical problem. Erroneous equations mean errors of rules which control behavior. In order to deal with such errors, the simulation must be a specific one, in which the behavior follows erroneous rules. We call such a simulation "Error-Based Simulation (EBS)." This framework is illustrated in Figure 8.

In order to generate EBS, however, a specific simulator is required. Equations in mechanics are rules of objects' behavior. A normal simulator, which is developed to generate simulation using correct rules, cannot deal with erroneous equations. Therefore, we have proposed EBS as a method to generate the simulation reflecting errors in rules. In other words, in the framework of EBS, the rules used to generate behavior simulation are different from the ones in correct simulation. We call this type of error-mapping "Rule-Error-Mapping."

Because the simulations generated by Rule-Error-Mapping are impossible ones in a real world, they should be used more carefully than the ones generated by Parameter-Error-Mapping. A learner, unfortunately, may get confused when the learner is shown EBS. Therefore, the management of EBS considering its effectiveness is indispensable.

4. Conclusion Remarks

In this paper, we described the qualitative diagnosis of EBS in order to evaluate visibility. EBS is a behavior simulation that reflects a learner's erroneous equation onto behavior simulation. Although EBS is a promising method to make a learner be aware of errors, it cannot always visualize the error. So, in order to manage EBS effectively, an evaluation of EBS is required. We have proposed the following factors to evaluate EBS: (1) visibility, (2) reliability, and (3) suggestiveness. The visibility is a factor related to whether or not EBS has enough difference from normal simulation. This factor is an essential factor of error-visualization. We have developed a module that evaluates EBS in visibility by using qualitative reasoning techniques. To realize management of EBS with the three factors is our future work.

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