Difference Visualization to Pull the Trigger of Reflection

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Abstract. In this paper, we propose a framework for scaffolding conflict awareness to pull the trigger of reflection in a metacognitive process. If a learner only monitors his/her action or results of it, he/she may not reflect them. When a learner finds something strange, the learner is motivated to carry out the reflection. To feel its strangeness, the learner should know the normal situation. Then the learner finds the difference between the observed thing and the normal thing he/she knows. The difference should also be significant for him/her. In short, when a learner is aware of a problem in his/her action or results, he/she motivates to reflect his/her knowledge. We call the awareness "Conflict Awareness". To visualize the difference is a promising approach to scaffolding the conflict awareness. In this paper, we propose Error-Based Simulation (EBS) as a method to visualize the difference targeting erroneous equations in physics problems. Control of the visualization is also described.

Introduction

In this paper, we propose a framework for scaffolding conflict awareness to pull the trigger of reflection in a metacognitive process. We also discuss the necessity of adaptive scaffolding and an approach to realize it.

The metacognitive process plays a crucial role in enhancing human problem solving capability. The process can be divided into the following two processes: one is a monitoring process where a learner observes his/her own action or results of the action, and the other is a reflection process where the learner reconstructs his/her knowledge based on the information collected in the monitoring process. Although the learning is carried out in the reflection process, the monitoring process is also important to motivate the reflection or to provide information for reflection. Scaffolding of the monitoring process is an important issue in computer-based learning environments [1].

If a learner only monitors his/her action or results of it, he/she may not reflect them. When a learner finds something strange, the learner is motivated to carry out the reflection. To feel its strangeness, the learner should know the normal situation. Then the learner finds the difference between the observed thing and the normal thing he/she knows. The difference should also be significant for him/her. In short, when a learner is aware of a problem in his/her action or results, he/she motivates to reflect his/her knowledge. We call the awareness "Conflict Awareness".

Visualization of the difference is a promising approach to scaffolding the conflict awareness. The most popular method is to map learner's actions or results onto another description where the difference becomes clear. We call this method "Difference Mapping". When the difference is visualized clearly as the result of the difference mapping, we call it "Difference Visualization". Our research objective is to realize scaffolding of the conflict awareness by the difference mapping and its adaptive visualization based on the evaluation of the difference visualization.

In this paper, first, we describe a model of reflection triggered by the difference visualization. Then, Error-Based Simulation (EBS) is described as a method to realize the difference visualization targeting erroneous equations of physics problems. Control of the visualization is also explained.

1. Scaffolding of Conflict Awareness

Figure 1 shows a model of reflection composed of the monitoring process and reflection process. To start the reflection, a learner should be aware of a conflict of the results of the monitoring. The conflict is arisen from the difference between observed results and expected results. However, the learner often fails to find the difference. Even if he/she found the difference, he/she often doesn't think it significant. In such cases, because the learner isn't aware of the conflict, the reflection isn't triggered.

To scaffold conflict awareness, difference mapping is a promising method. Figure 2 shows the framework. The most fundamental factor for the conflict awareness is (1) visibility that is an evaluation of the difference between the mapped learner's action and the mapped learner's prediction. However, the visibility is not the only factor to evaluate the effectiveness of the difference mapping. We propose two more factors, that is, (2) reliability and (3) suggestiveness. The reliability is related to whether or not the learner depends on the difference visualized by the difference mapping. The suggestiveness is a factor related to whether or not the difference suggests the way to reflection. In the next section, a work-in-progress toward adaptive scaffolding of conflict awareness with the above three factors is introduced.

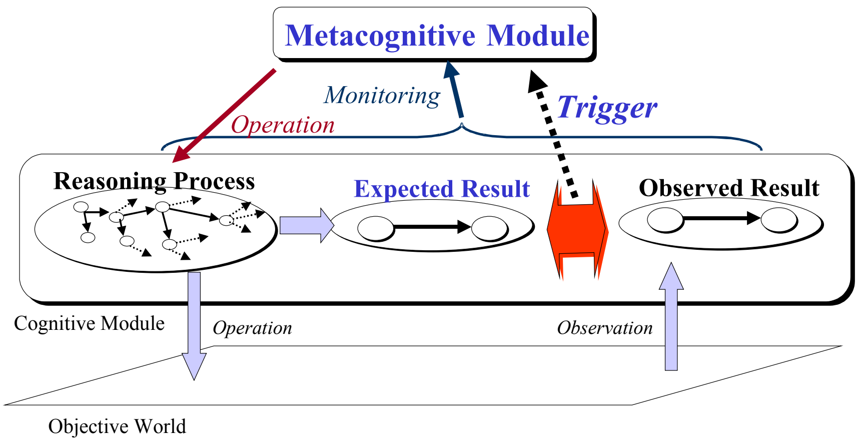

Figure 1. A Model of Reflection.

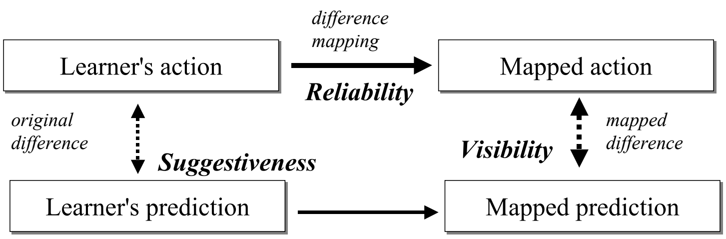

Figure 2. A Framework of Differencce Visualization.

2. Error-Based Simulation: EBS

As a concrete method of the differential visualization, we introduce EBS. Figure 3 shows the framework of the difference visualization with EBS [2]. EBS is a method to generate strange behavior simulation from an erroneous equation made in solving a mechanics problem. 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. Because an error in an erroneous equation is visualized as the difference between the normal simulation and EBS, we call this difference visualization "error visualization".

In Figure 4, 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.

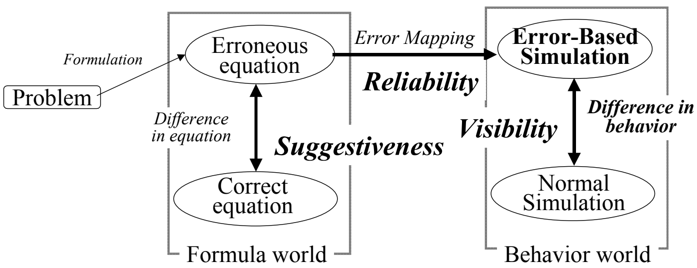

Figure 3. A Framework of Error-Based Simulation.

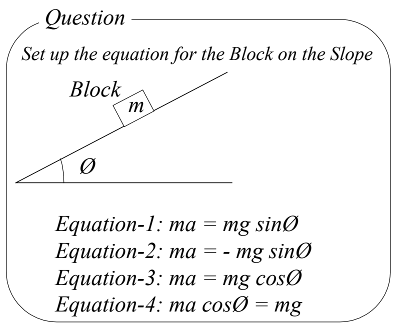

Figure 4. An Example of Mechanics

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 4, 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 θ 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 4, 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 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 4, 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 θ satisfies CEV-2. Then, the EBS is judged to have satisfactory visibility due to perturbation of θ. 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 [3,4].

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 4, "visible" EBS can also be generated by using a boundary value, in this case, $\theta = 0$ or $\theta = 90$. In the EBS with $\theta = 0$ (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 θ (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 looked too different from the original system while the one in EBS-2 didn'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 by perturbation method is smaller that the change by boundary value method. So, we use the following preference: [no modification] > [perturbation] > [boundary value]. "No modification" means to use raw EBS. This preference is discussed in [4].

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)" in [5].

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 [6] is used to predict the qualitative behaviors. When a qualitative difference in the velocity or acceleration is found, the EBS-manager judges that the 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 [7] 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: $0 < \theta < 90$. Although an equation of motion of an object on a slope is valid when $\theta = 0$ or $\theta = 90$, 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'. 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 5 (initial velocity is added to the problem in Figure 4), 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 5, 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.

Equation-A: ma = mg sinƒ Æ　　Equation-B: ma = -mg sinƒ Æ
(Initial Velocity : v0 > 0)　　(Initial Velocity : v0 > 0)

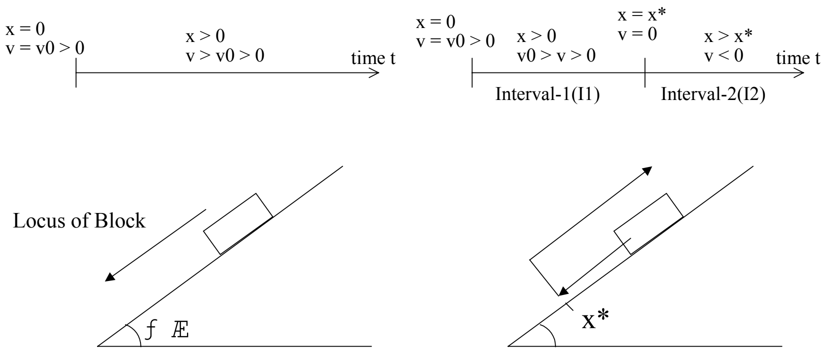

Figure 5. The Intervals in which EBS has Qualitative Differences from a Normal Simulation.

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 [7]. 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." 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'. 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 6 (the same problem as Figure 4), 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, θ 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 θ increases acceleration of the Block in the normal simulation, while increasing θ decreases acceleration of the Block in the EBS.

Equation-A: ma = mg sinƒ Æ
When ƒ Æincreases:
v: increases
a: increases

Equation-C: ma = mg cosƒ Æ
When ƒ Æincreases:
v: decreases
a: decreases

(Length of the arrows indicates the magnitude of velocity and acceleration)

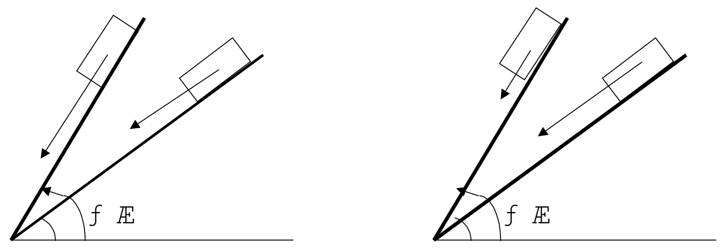

Figure 6. An Example of the Parameter of Which Perturbation Causes a Qualitative Difference.

4. Related Works in Error-Visualization

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 7. 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 [8,9].

The second is illustrated in Figure 8. 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 [10], 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 erroneous 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 9.

However, there are not a few learners who formulate erroneous equations in solving mechanical problem. Erroneous equations mean errors of rules that 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 10.

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.

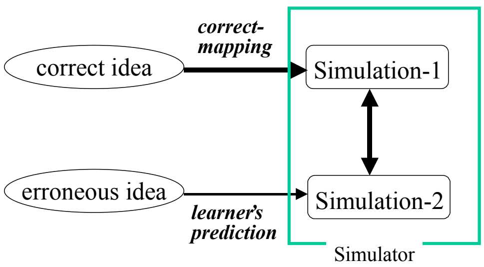

Figure 7. Correct-Mapping.

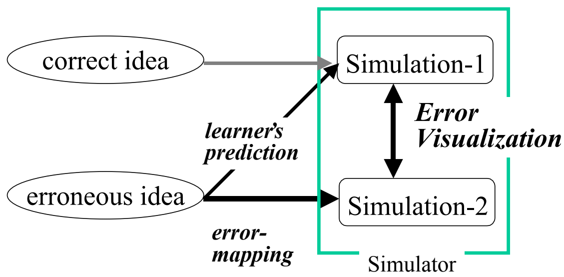

Figure 8. Error-Mapping.

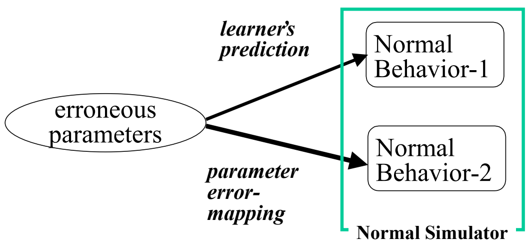

Figure 9. Parameter-Error-Mapping.

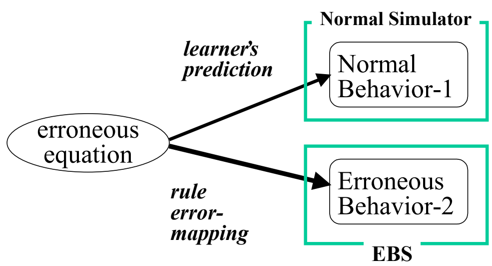

Figure 10. Rule-Error-Mapping.

5. Conclusion Remarks

In this paper, a framework for scaffolding conflict awareness to pull the trigger or reflection in a metacognitive process was proposed. Based on the framework, difference visualization was proposed in order to let a learner be aware his/her mistake. As a concrete method of the difference visualization, Error-Based Simulation that is a method to generate strange behavior simulation from an erroneous equation made in solving a mechanics problem was introduced. Management of the visualization based on the evaluation of the visibility of the EBS was also explained.

Although we believe our approach is promising, experimental evaluation of the EBS as a trigger of reflection is not carried out. This is not an easy task but the results will contribute to improve the EBS and our framework for promoting a learner reflect their knowledge and thinking. Therefore, investigation of effect of the EBS is our future work. Making clearer the relations between theories or empirical studies of metacognition and our framework is also our future work.

Moreover, EBS can only deal with the equations of physics. EBS may be able to apply several well-defined domains similar to physics. Even in such well-defined domains, it is difficult for learners to be aware of their errors and there is few investigation of adaptive scaffolding of the awareness. Therefore, our current research target is to formalize the framework of the differential visualization with EBS in the well-defined domains. The expansion to less well-defined domains is the following step.

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