Chen, W. et al. (Eds.) (2017). Proceedings of the 25th International Conference on Computers in Education.
New Zealand: Asia-Pacific Society for Computers in Education

Development of a System to Construct Explanation for Physics Phenomenon through Thought Experiment

Miki MATSUMURO[a*], Kazuhisa MIWA[a] & Yuiko TOMBE[b]
[a]*Graduate School of Informatics, Nagoya University, Japan*
[b]*Graduate School of Information Science, Nagoya University, Japan*
*muro@cog.human.nagoya-u.ac.jp

Abstract: This study focused on thought experiments (TEs) as a strategy to modify students' incorrect internal mental models and aimed to develop a system to externalize TEs in students' mind. A TE is an experiment conducted in the mind. Our system, called Thought Experiment Externalizer (TE-ext), provided some situations where TEs were conducted. The students externalized the results of their TEs on a PC display using the TE-ext. We tried to modify the student' incorrect internal model and their incorrect explanation of surprising data using the system. The students were able to improve their explanation, which means that they were able to modify their internal models.

Keywords: Thought experiment, explanation, science education system, physics

1. Introduction

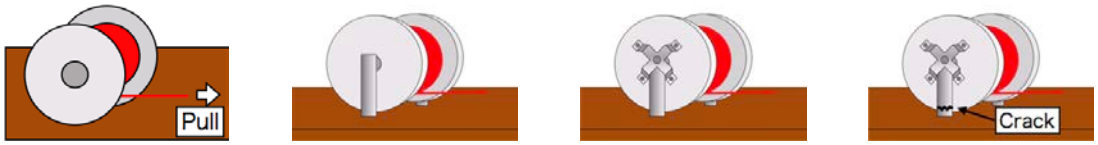
When we try to understand the world or solve problems, we construct an internal representation of an abstract world or the problem situation, called an internal model (Anzai & Yokoyama, 1984). Students often construct incorrect internal models based on their daily experience (Anzai & Yokoyama, 1984; Brown, 1993; Vosniadou & Brewer, 1992). We focused on thought experiments (TEs) as a strategy to modify students' incorrect internal models.

A TE is an experiment conducted in one's mind. The first step of a TE is to imagine a situation where an experiment is conducted (Kösem & Özdemir, 2014; Reiner, 2006). In the context of education (e.g., Clement, 1993; Smith, 2007), teachers give the most effective TE scene. TE users then carry out operations, such as pushing, pulling, or dropping an object. Finally, they see the results of the operation in their minds. The result is derived from their knowledge or memories, or from mental simulations (Clement, 2009; Hegarty, 2004). Although TEs do not provide new knowledge or information, it invokes knowledge unused in the original problem. In this paper, we introduce our system called a Thought Experiment Externalizer (TE-ext), which helps the students modify their internal models and construct a correct explanation for a physical phenomenon.

2. Thought Experiment Externalizer

2.1 Material

We used the yoyo problem from Anzai and Yokoyama (1984). The problem was to predict the movement of the yoyo in Figure 1(a). The correct answer was that the yoyo would rotate clockwise and roll to the right. The direction of rotational momentum caused by the tension force and the center of rotation at the yoyo's point of contact with the floor determined the movement. However, according to the students' naïve model, the yoyo's axis was the center of rotation. They answered that the yoyo would rotate counterclockwise and roll to the left.



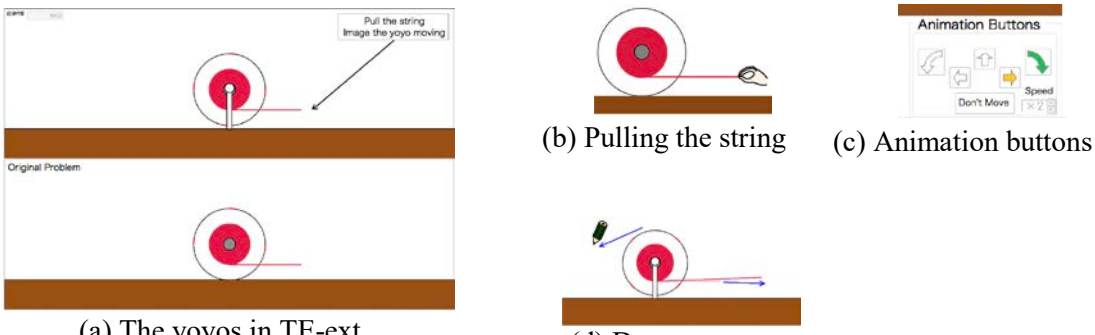
(a) Original Problem (b) Axis Scene (c) Fixed Scene (d) Broken Scene

Figure 1. Original yoyo problem and three scenes in the scenario.

2.2 System's Function

The TE-ext is a tool externalizing students' TEs on a PC display. The display is divided horizontally; a specific TE scene is given above and the original yoyo problem scene is below (Figure 2(a)). The students pull the string as shown in Figure 2(b) and imagine how the yoyo will move (the yoyo on the display does not move at this point).

The students can move the yoyo in the display by selecting directions and pulling the string again (Figure 2(b), 2(c)). The yoyo in TE-ext moves in accordance with the selected buttons, even if such movement violates physical laws. The role of TE-ext is only to externalize TEs; in a mental simulation, any prediction is possible. Then the students consider why the yoyo moves as they imagined, drawing arrows on the display (Figure 2(d)).



(a) The yoyos in TE-ext (b) Pulling the string (c) Animation buttons

(d) Drawn arrows

Figure 2. Sample screenshots of TE-ext.

2.3 Scenario

A TE scene is given according to a scenario consisting of three TE scenes in Figure 1. In the axis scene (Figure 1(b)), we put a stick through the center of the yoyo and set it between two sticks fixed on a table. This was a familiar scene to the students, reminding them of such as a toilet paper holder. They would easily imagine the yoyo rotating counterclockwise from their daily experiences. Then we fixed the yoyo to the sticks in the fixed scene (Figure 1(c)). The yoyo would not move as the string was pulled.

The broken scene (Figure 1(d)) was the successor to the fixed scene. The instructions for this scene were as follows: "You have kept pulling the string of the fixed yoyo. As a result, the sticks almost break. If you pull the string again, they will break completely." This scene was identical to that of an object standing on a table being pulled to the right. The yoyo and sticks would fall down to the right, rotate clockwise and move to right.

*3. **Test of the effect of the TE-ext***

3.1 Participants and Procedure

Twenty-three undergraduate students participated. First, we demonstrated the movement of the yoyo in the original problem. Following the demonstration, the students gave an explanation as to why the yoyo moved as shown in the demonstration as the pre-test.

After the pre test, the students considered why the yoyo in the original problem rotated clockwise and moved to the right using the TE-ext for 30 minutes. After the thinking time, the students saw the demonstration and gave an explanation again as the post-test.

3.2 Results

Four students were excluded from the analysis, because they did unrelated things. The students' explanations were scored from 0 to 3 point. If the students continued to work with the incorrect internal model, their explanations were scored 0 point. We gave 1 point, if they related the direction of the pulling the string and the movement of the yoyo. For example, "the experimenter pulled the string to the right, so the yoyo moved to the right and rotated clockwise." A score of 2 points was given to the explanations that described the pulling tension affecting the whole of the yoyo. Explanations implying that the student understood that the yoyo rotated clockwise because its point of contact with the table did not move (i.e., the center of the rotation) were given the score of 3 points. The score in the post-test was higher than that in the pre-test significantly (pre $M = 0.684$, $SD = 1.003$ vs. post $M = 1.368$, $SD = 1.012$; $t(18) = 2.233$, $p = .038$).

4. Discussion

The explanations of the students were improved using the TE-ext. They were able to modify their internal model. They learned the forces exerted on the yoyo from each scene and applied this knowledge to the original problem. Some might think that the students would always modify their internal models if they were given surprising results. However, previous studies have shown that even if they receive a surprising result, students resist modifying their models (Chinn & Brewer, 1993). Almost half of the students (57.89%) tried to make explanations without modifying their internal model (score 0) in the pre test in this study.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number JP 15H02927.

References

Anzai, Y., & Yokoyama, T. (1984). Internal models in physics problem solving. *Cognition and Instruction*, *1*, 397-450.

Brown, D. (1993). Refocusing core intuitions: A concretizing role for analogy in conceptual change. *Journal of Research in Science Teaching*, *30*, 1273-1290.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research*, *63*, 1-49.

Clement, J. J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. *Journal of Research in Science Teaching*, *30*, 1241-1257.

Clement, J. J. (2009). The role of imagistic simulation in scientific thought experiments. *Topics in Cognitive Science*, *1*, 686-710.

Hegarty, M. (2004). Mechanical reasoning by mental simulation. *Trends in Cognitive Sciences*, *8*, 280-285.

Kösem, Ş. D., & Özdemir, O. F. (2014). The nature and role of thought experiments in solving conceptual physics problems. *Science & Education*, *23*, 865-895.

Reiner, M. (2006). The context of thought experiments in physics learning. *Interchange*, *37*, 97-113.

Smith, C. L. (2007). Bootstrapping processes in the development of students' commonsense matter theories: Using analogical mappings, thought experiments, and learning to measure to promote conceptual restructuring. *Cognition and Instruction*, *25*, 337-398.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, *24*, 535-585.