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Students' Virtual Experiment Behavior Using an Interactive Simulation

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Abstract: In this paper, we introduce our newly developed interactive simulation that allows students to conduct virtual experiments to learn how ionizing radiation affects living things. Twenty-three seventh-grade students in Taiwan participated in this study and used the interactive simulation to conduct virtual experiments during their science class. The study identified and investigated nine different types of virtual experiment behavior. Moreover, the results indicated that three kinds of virtual experiment behavior significantly related to how well the students conducted controlled experiments, including (1) whether or not the students inspected all the objects before experimenting, (2) the extent to which the students conducted convergent experiments, and (3) the number of experiments started. Implications of the results are discussed.

Keywords: virtual experiment, behavior, interactive simulation, science learning

1. Introduction

Interactive computer simulations allow learners to conduct virtual experiments that cannot easily be conducted in real-life situations (Chang, 2016). Learners can change the parameters and values of the simulation to test their hypotheses and theories. In this study, a newly developed interactive simulation focuses on the issue of how ionizing radiation may impact living things. Nuclear pollution that involves ionizing radiation has been a concern of nuclear power development locally and globally. Students as future global citizens need to learn the mechanism of how ionizing radiation affects living things in order to make informed decisions about the issue of nuclear power development (Jho, Yoon, & Kim, 2014). Virtual experiments using interactive simulations are particularly suitable for this topic since ionizing radiation can be harmful, and it is not possible for students to conduct real experiments using ionizing radiation.

However, students may have difficulties conducting mindful and purposeful virtual experiments, given the openness of the interactive simulation environment (Lee, Nicoll, & Brooks, 2004; Moreno & Valdez, 2005; Parnafes, 2007). One major difficulty involves students' inability to conduct purposeful controlled virtual experiments (McElhaney & Linn, 2011). Purposeful controlled experiments require students to consider the investigation goal and conduct unconfounded experiments using the "varying one variable at a time" technique. Researchers have started to develop data mining techniques to investigate learners' virtual experiment behavior (Gobert, Sao Pedro, Raziuddin, & Baker, 2013). As an initial step, this study examined a class of junior high school students' virtual experiment behaviors by analyzing process videos that captured the students' interactions with the simulation. This study further investigated which aspects of the behavior can significantly predict the behavior of conducting controlled experiments. The results of this study provide insights for curriculum developers to consider how to design effective learning environments to support students in developing their ability to conduct purposeful controlled experiments.

2. The Interactive Simulation

The simulation was developed by a group of science educators, biology teachers, and medical experts. It is virtually contextualized as taking place in the garden of a school that contains objects including various plants and human beings. A virtual emitter of ionizing radiation is located on the lower right corner of the screen (Figure 1) for students to set up the dose of the ionizing radiation. Students then drag the emitter to choose the object receiving the radiation. After that, a window emerges in which students can select to view animations showing the impact of the radiation on that object at the microscopic level (an example is shown on the left in Figure 2) or macroscopic level (on the right in Figure 2). Students can review their experiments by clicking the “record of data” button that shows all the radiation values the students have set up and the microscopic and macroscopic results. A follow-up activity guides the students to infer from their data and observation of the animations the amount of ionizing radiation that can cause different degrees of damage to plants and animals, and the mechanism of how the damage occurs.

Figure 1. Screenshot of the interactive simulation.

Figure 2. Result animations showing the impact of the given dose of the ionizing radiation on the selected living thing. Left: at the microscopic level. Right: at the macroscopic level.

3. Methods

3.1. Participants and Procedure

One class of 23 seventh-grade students (11 female) at a public junior high school in Taiwan participated in this study. The second author taught the science class that incorporated the simulation in the unit of radiation and energy. In the unit, the students were guided to learn the definition of ionizing radiation and its impact on ecology (three class periods). This study particularly focused on the learning activity in which the students explored the simulation and conducted virtual experiments for about half of a class period (45 minutes). Each student worked on one computer. The students were encouraged to discuss with their peers and the teacher. The students had little experience of using computer simulations prior to this study.

3.2. Data Collection and Analysis

The students' behavior of conducting virtual experiments was recorded using the screen-capture software, Camtasia. Referring to the experiment behavior investigated in Gobert et al. (2013), we reviewed the recorded process videos to generate a scheme of the students' virtual experiment behavior, which is discussed in the results section. The second author and another independent coder coded the behavior of 8 students based on the scheme, and their agreement reached 84%. Inconsistent codes were discussed and resolved. The second author then coded the rest of the process videos.

Descriptive statistics were employed to indicate the distribution of the students' virtual experiment behavior. Moreover, an exploratory multiple regression analysis was conducted to investigate whether any of the students' virtual experiment behaviors were a significant predictor of their performance of conducting controlled experiments. Therefore, the multiple regression model included the 8 types of virtual experiment behavior as the predicting variables, and the controlled experiment variable as the outcome variable. This model explained 83.2% of the variance in the students' controlled variable performance, indicating that the regression model is appropriate.

4. Results

4.1. The Students' Virtual Experiment Behavior

We summarized the nine different types of virtual experiment behavior identified in Table 1. Overall, only 8.7% of the students inspected all objects before starting the experiments. That is, the majority of the students did not inspect what objects were available prior to their experiments. On average, the number of objects tested per student was 8.48, given that the maximum number of objects available for testing was 12. Each student started about 20 experiments, but only completed 4.61 on average. The number of completed experiments is low because many students did not click to observe the microscopic animation showing the result of the experiment at the microscopic level.

Moreover, the mean number of changing the radiation values is about 10 times per student. On average, each student viewed the datasheets three times. Very few students conducted repeated experiments in which none of the values or objects were changed. About one-fifth of the experiments conducted focused on the same object. As for the number of controlled experiments, the mean number per student is about 16 times, with the minimum of 4 and the maximum of 29. It seems that all of the students conducted controlled experiments, but this could be either intentionally or unintentionally.

Table 1: Types, definitions and results of the students' virtual experiment behavior.

Type	Definition	Result
1. Inspection of all objects available	Whether the student inspected all objects before starting experiments.	Yes: 8.7% No: 91.3%
2. Number of objects tested	The number of objects the student selected to receive radiation.	8.48 [a] (2.73 [b])
3. Number of times starting an experiment	The number of times the student clicked "start" to start an experiment.	20.22 (6.45)
4. Number of times completing an experiment	The number of times the student completed an experiment, including setting up values, experimenting, and viewing the macro- and microscopic animation results for that experiment.	4.61 (5.68)
5. Number of times changing the radiation values	The number of times the student changed the radiation values.	10.17 (4.55)
6. Number of viewing datasheets	The number of times the student viewed the datasheets.	3.04 (1.43)
7. Number of times repeating an experiment	The number of times the student conducted two identical experiments (same value, same object).	0.17 (0.49)
8. Percentage of series experiments on the same object	The percentage of the number of times an experiment focused on the same object divided by the total number of experiments.	19.40 (19.51)
9. Number of controlled experiments	The number of times the student changed only one variable and controlled the other variables between two experiments.	15.87 (7.22)

a: mean; b: standard deviation in parentheses

4.2. Factors Related to the Controlled Experiment Behavior

The multiple regression results indicated that only three types of virtual experiment behavior were significantly related to the variable of controlled experiments, namely inspection of all objects, number of times changing the radiation values, and number of times starting an experiment. We summarize the results only for the significant factors in Table 2.

As revealed in Table 2, the students who inspected all objects before they started the experiments were more likely to be able to conduct controlled experiments. In contrast, changing the radiation values more often had a negative effect, given that the coefficient is negative. In other words, the students who changed radiation values more often were less likely to conduct controlled experiments. Moreover, the students who started more experiments were more likely to conduct controlled experiments.

Table 2: Multiple regression results.

Model	Unstandardized Coefficients B	SE	Standardized Coefficients Beta	t	Sig.
(Constant)	7.08	4.07		1.74	.104
Inspection of all objects	9.00	2.75	.36	3.27	.006
Number of times changing the radiation values	-1.17	0.26	-.74	-4.47	.001
Number of times starting an experiment	1.26	0.17	1.13	7.31	<.001

5. Conclusion and Discussion

In this study, we found that very few students demonstrated the "inspection of all objects available" behavior prior to their experiments. However, this behavior was significantly related to the extent to which the students conducted controlled experiments. Among the nine types of experiment behavior identified, we think that this inspection behavior is mostly related to metacognition, since it may involve planning and monitoring, which are important aspects of metacognition (Baker & Brown, 1984). Research has found that scaffolding students' self-monitoring skills can enhance their learning with visualizations (Chiu & Linn, 2012). In this study, we provide evidence that students being able to inspect all objects available significantly predicted their behavior of conducting controlled virtual experiments using interactive simulations. Future research can consider designing instructional activities to guide students to inspect the context before experiments to formulate experimental goals. We believe that this strategy will enhance students' ability to conduct purposeful controlled virtual experiments. Future investigations can develop instructional activities and include more participants to test this claim.

One limitation of this study involves the relatively small number of participants. Nevertheless, we were able to thoroughly investigate the virtual experiment behavior of the participants, and identified nine types of behavior, among which three were significantly related to the extent to which the students conducted controlled experiments. In addition to the "inspection" behavior that has been discussed, we found that students who conducted divergent experiments that involved the behavior of setting up a greater variety of radiation values were less likely to conduct controlled experiments. It seems that encouraging this group of students to conduct convergent experiments instead may help. However, research also indicates that allowing students to explore simulations may provide opportunities and time for them to set up their conceptual framework for mindful engagement (Adams, Paulson, & Wieman, 2009). It seems that in our study the students were arbitrarily changing the values rather than mindfully exploring the simulation. Developers of learning environments need to differentiate these two types of student behavior and provide different types of scaffolding to address different student needs.

It seems reasonable that students who started more experiments had greater chances of conducting controlled experiments, as we found a positively significant relationship between students starting more experiments and conducting more controlled experiments. This finding also supports the perspective of Adams et al. (2009) that free exploration of simulations may benefit student learning. Moreover, one advantage of virtual experiments using computer simulations is that it does not cost or result in damage when error or trial experiments are conducted. The trial-and-error strategy may be effective for some students. Students should not be restricted to a certain procedure of conducting virtual experiments. Nevertheless, how to challenge and scaffold students to purposefully conduct controlled experiments with their appropriate developmental needs for deep and effective learning needs further investigation.

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