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Pedagogy Designs to Augment the Impact of Computer Simulations

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Abstract: In this study, we compare the effects of two different pedagogical designs around a computer simulation on students' scientific literacy in the case of learning science concepts relating to sinking and floating. We also compare the effects of teaching with simulations versus traditional teaching to provide baseline information. A total of 75 eighth-grade students participated in the study. Data collected include the students' pretest and posttest data that indicate scientific literacy. The results provide evidence for the effectiveness of a student-centered pedagogical design. Reflection and discussion on how to augment the impact of computer simulations are provided.

Keywords: Pedagogy designs, computer simulations, critique, scientific literacy

1. Introduction

Computer simulations allow learners to conduct virtual experiments such as changing the parameters and values of the simulation to test their hypotheses and theories, enabling learners to engage in core authentic scientific practices, especially on phenomena that cannot easily be observed or investigated in real-life situations. However, students may have difficulties conducting mindful and purposeful virtual experiments, given the openness of the interactive simulation environment (McElhaney, Chang, Chiu, & Linn, 2015). Therefore, teaching guidance is needed to support learners' inquiry with interactive simulations to conduct productive and mindful virtual experiments (Efstathiou et al., 2018). How to design effective pedagogies for teaching with computer simulations to address students' difficulties and promote their science learning has become an important issue.

In this study, we worked with two science teachers at the participating school to create two versions of pedagogy designs for a computer simulation focusing on the phenomenon of sinking and floating, which has been developed via the CoSci platform (http://cosci.tw/). One version involves teacher demonstration, and the other involves students' critique activities (detailed in the next section). We compared the effects of the two designs on students' performance of scientific literacy after the treatments. Both of the designs are for teaching with simulations. Since the unit of sinking and floating is usually taught conventionally without the use of simulations, we were also interested in how the effects of teaching with simulations compared to the effect of conventional, lecture- and textbook-based teaching. The learning outcome focused on is students' scientific literacy in the context of phenomena relating to sinking and floating. Developing future citizens' scientific literacy involves the goal of educating young people to become critical users of scientific knowledge, including developing their ability to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically (OECD, 2016). This goal has been emphasized in science education standards in Taiwan (Taiwan Ministry of Education, 2014) and globally (e.g., NGSS Lead States, 2013). The results of this study provide insights into how to develop effective pedagogies around computer simulations to foster students' scientific literacy.

2. Pedagogy Designs for Teaching with Computer Simulations

2.1 The Teacher Demonstration Design/Treatment

In the teacher demonstration treatment, the teacher spent one class period (45 minutes) demonstrating how to conduct experiments with the CoSci sinking and floating simulation. She selected one inquiry question provided in the CoSci simulation learning environment and showed her students how to formulate hypotheses, design and conduct virtual experiments, collect and analyze data and make conclusions to address the inquiry question. All materials needed for the demonstration were prepared in advance as PowerPoint slides. During the demonstration the teacher lectured following the slides and occasionally paused to ask students questions to engage them in the lecture. Then the students were allowed to conduct their own inquiry with the simulation for two class periods. The students' inquiry was guided by the system through provided inquiry questions and prompting hints and questions.

2.2 The Student Critique Design/Treatment

In the student critique treatment, the students worked on worksheets prepared by the science teachers that asked the students to critique fictitious experiments with the CoSci sinking and floating simulation. For example, the students were given an inquiry question and a series of experiment designs and were asked to critique "whether these designs can answer the inquiry question or not? If not, how can you improve the designs?" The students were also asked to critique whether a given set of data could be used to support a given conclusion, and how to improve the conclusion. The students spent one class period completing the critique worksheets. The teacher also led whole class discussions to engage the students in discussing their critiques. Then the students were allowed to conduct their own inquiry with the simulation for two class periods. The students' inquiry was guided by the system through provided inquiry questions and prompting hints and questions. The design of the student critique activities was based on Chang and Linn (2013) who indicated that critiques involving reflection facilitate knowledge integration.

3. Methods

Three classes of eighth-grade students at a public junior high school in Taiwan participated in this study. Each class was randomly assigned to one of the three treatments: teacher demonstration followed by student inquiry with simulation (n=24), student critique followed by student inquiry with simulation (n=26), or traditional lecture without student inquiry with simulation (n=25). The first two involved the use of the CoSci simulation (as detailed in the previous section). The traditional lecture treatment also involved three class periods but teaching through lecture- and textbook-based lectures with no simulation. The three groups did not differ in terms of their prior scientific literacy as measured by the pretests [$F(2, 72)=0.085$, $p=.919$].

Each individual student took pretests before (about one class period) and posttests after (about one class period) the treatment. The pretests consisted of eight constructed-response items to measure students' scientific literacy in the context of near transfer from the context of the simulation. In addition to the eight items, the posttests (a total of 14 items) comprised six additional items that measured students' scientific literacy in the context of far transfer from the context of the simulation. The items went through several rounds of revision by three science educators to ensure content and construct validity.

Detailed scoring rubrics were developed to score students' scientific literacy performance. 20% of the tests were coded by two independent coders following the rubrics, and the inter-coder agreement reached 96%, with Cohen's Kappa = 0.94. ANCOVA was employed to test the differences among the three treatments, using the posttest score as the dependent variable, the pretest score as the covariate, and the treatment as the independent variable. In addition, we calculated effect sizes between any two mean scores of the posttests with the difference between two means divided by the combined standard deviation for those means, according to Cohen (1988).

4. Results

The students' pretest and posttest mean scores and standard deviations are summarized in Table 1. The ANCOVA result indicates that there is a significant treatment effect ($F=7.908$, $p=0.001$). Paired comparisons with a modified Bonferroni correction reveal significant differences between the Student

Critique treatment and the traditional teaching treatment, but no significant difference between any two of the others. The effect sizes are large between any two of the three treatments, given that the mean differences are large and the standard deviations are very small. Overall, the results indicate that the effect of teaching with the sinking and floating computer simulation can be augmented by the pedagogical design that engages students in critiquing experiments with simulations prior to their inquiry with the simulation. This effect is specifically significant when compared to traditional teaching that employs lecture- and textbook-based approaches.

Table 1

Pretest and Posttest Means, Standard Deviations (in Parentheses), and Effect Sizes

	Pretest	Posttest	Effect Size (d)
Teacher Demo Treatment	8.71 (4.11)	11.82 (0.75)	Student Critique/ Teacher Demo= 2.96; Teacher Demo/ Tradition =2.51; Student Critique/Tradition= 5.61
Student Critique Treatment	9.23 (3.64)	13.97 (0.70)	
Traditional teaching Treatment	8.92 (5.58)	9.96 (0.73)	

5. Concluding Remarks

The study provides evidence that coupling computer simulations with student-centered critique activities can better benefit students' scientific literacy than the traditional lecture approach. Although the teacher demonstration approach coupled with student inquiry with simulations had a large effect compared to the traditional approach, this effect did not reach statistical significance. Also, the relative effect between the teacher demonstration and student critique approaches is large but not significant. In a previous study (Wen et al., under review) we found that the effect of student inquiry with simulation on students' scientific literacy would significantly appear in delayed posttests but not in posttests based on the growth of a learning curve for literacies (Horton, 2001). We are conducting and collecting data using delayed posttests to further discern the effects of the treatments.

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