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Path Analyses of How Students Develop Conceptual Knowledge and Inquiry Skills in a Simulation-Based Inquiry Environment

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Abstract: We implemented a simulation-based learning environment in a summer camp program in which 45 ninth-grade students conducted virtual experiments using computer-based simulations to learn the concepts of buoyancy. We collected data including all students' responses to the pretests, assessments embedded during class in the learning environment, and posttests. All the tests measured the students' conceptual knowledge of buoyancy and inquiry skills. We conducted path analyses to investigate how the students developed their conceptual knowledge and inquiry skills during and after learning within the learning environment. A common significant path is identified among students' prior knowledge and skills and students' developed knowledge and skills.

Keywords: Computer-based simulation, virtual experiment, inquiry, science, path analysis

1. Introduction

Computer-based simulations enable human-computer interactions that can allow students to conduct virtual experiments using simulations. Compared to hands-on experiments, virtual experiments are equal to or more effective for enhancing students' understanding of scientific concepts due to their technological efficiency and their ability to provide ideal experiment conditions (Klahr, Triona and Williams, 2007; Zacharia, Olympiou and Papaevripidou, 2008). However, it is unclear how students develop their conceptual knowledge in a simulation-based virtual experiment environment as they conduct inquiries. Some research indicates that the development of conceptual knowledge and inquiry skills are often interwoven (Bao, Gotwals, Songer and Mislevy, 2006). Despite this, it is possible to measure conceptual knowledge and inquiry skills separately (e.g., P.-H. Wu, H.-K. Wu and Hsu, 2013), and to discern how conceptual knowledge and inquiry skills are interwoven at multiple time-points such as before, during, and after class. Specifically, we are interested in, in a simulation-based inquiry learning environment, how students' prior knowledge and prior inquiry skills affect their knowledge and inquiry performance during class, and in turn after class in the posttests.

2. The Simulation-Based Inquiry Environment

The inquiry learning environment incorporates a newly developed simulation for students to conduct virtual experiments to learn factors related to an object sinking or floating in a given fluid. The students can change the values of four variables in the simulation to conduct their experiments (Figure 1): (1) the material of the object (duck): brick, wood, ice, styrofoam, or steel; (2) the size of the object (duck): large, medium or small; (3) the composition of the duck: solid or hollow; and (4) the type of fluid: water, saline water, gasoline, or mercury. In addition, on the upper right hand side of Figure 1, four virtual probes are provided so that the students can use them to measure the volume, mass, density or buoyant force of the object, and the density of the liquid. A small pop-up window appears on the left side to indicate the volume of the fluid displaced after the duck is placed in the fluid. The students were asked to synthesize from their experiments, and to reason the variables directly related to the phenomenon of sinking and floating. In addition, we embedded a function in the simulation for the students to create a worksheet of their experiments recording the properties of the ducks and fluids they experimented with (Figure 2). Using the worksheets, the students were guided to reason that for a floating object, the buoyant force is equal to the weight of the object, and that for a sunken object (and a floating object), the buoyant force of the object in a fluid equals the density of the fluid times the volume of the object immersed in the fluid. Moreover, they were guided to draw their visualizations of the buoyant forces acting upon floating and sunken objects.

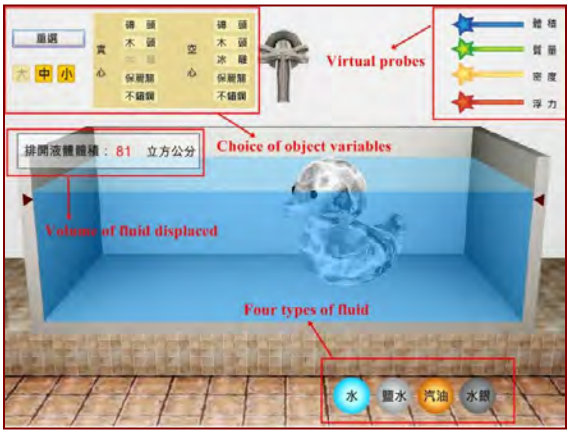

Figure 1. A screenshot of the *bath duck* simulation that allows students to conduct virtual experiments

實驗次數	ID	步驟	物體	實心/空心	是否為沉體	物體所受浮力(gw)	物體在液面下體積(cm³)	液體與其密度(g/cm³) 油:0.7 水:1 鹽水:1.1 水銀:13.6	物體重量(gw)
1	fl10230325	2.3	小木鴨	實心	浮體	15	15	水:1	15
2	fl10230325	2.3	中冰鴨	實心	浮體	54	54	水:1	54
3	fl10230325	2.3	大磚鴨	空心	沉體	135	90	水:1	90
4	fl10230325	2.3	小保麗龍鴨	空心	浮體	2.1	2.1	水:1	2.1
5	fl10230325	2.3	大鋼鴨	實心	沉體	270	90	鹽水:1.1	99
6	fl10230325	2.3	中木鴨	空心	浮體	18	25.7	油:0.7	18
7	fl10230325	2.3	大冰鴨	實心	浮體	81	6	水銀13.6	81
8	fl10230325	2.3	中磚鴨	空心	浮體	90	6.6	水銀13.6	90
9	fl10230325	2.3	大鋼鴨	空心	浮體	45	45	水:1	45
10	fl10230325	2.3	小木鴨	實心	浮體	15	15	水:1	15
11	fl10230325	2.3	大冰鴨	空心	浮體	45	45	水:1	45
12	fl10230325	2.3	中鋼鴨	實心	沉體	180	60	水:1	60
13	fl10230325	2.3	大保麗龍鴨	空心	浮體	6.3	6.3	水:1	6.3
14	fl10230325	2.3	小磚鴨	空心	沉體	45	30	水:1	30
15	fl10230325	2.3	中磚鴨	實心	沉體	120	60	水:1	60
16	fl10230325	2.3	中保麗龍鴨	實心	浮體	12	12	水:1	12
17	fl10230325	2.3	小冰鴨	空心	浮體	15	15	水:1	15
18	fl10230325	2.3	大木鴨	實心	浮體	45	40.9	鹽水:1.1	45
19	fl10230325	2.3	小磚鴨	空心	沉體	45	30	鹽水:1.1	33
20	fl10230325	2.3	中鋼鴨	實心	沉體	180	60	油:0.7	42
21	fl10230325	2.3	中冰鴨	空心	浮體	30	2.2	水銀13.6	30
22	fl10230325	2.3	小木鴨	實心	浮體	15	1.1	水銀13.6	15
23	fl10230325	2.3	大保麗龍鴨	實心	浮體	18	1.3	水銀13.6	18
24	fl10230325	2.3	小木鴨	空心	浮體	9	0.700005	水銀13.6	9
25	fl10230325	2.3	中磚鴨	空心	浮體	90	6.6	水銀13.6	90

Figure 2. A computer-generated worksheet recording the student's experiments

3. Methods

The study involved 45 ninth-grade students who volunteered to participate in a summer science camp program at a public high school in North Taiwan. These students demonstrated high interest and motivation in learning science. They had not learned buoyancy prior to this study. The students spent 4 hours to complete their learning in the environment with the guidance of a science teacher. Each individual student took a pretest before and a posttest after. The pretest and posttest were identical and included two parts. The first contained 8 items to measure the students' conceptual knowledge of buoyancy. The second part contained 15 items to measure the students' inquiry skills including planning experiments, identifying variables, conducting reasoning, using evidence and evaluating explanations. The items went through several rounds of revision by science educators to ensure their content and construct validity. In addition to the pretest and posttest, another 8 conceptual items and 11 inquiry items were embedded in the learning environment to measure the students' conceptual knowledge and inquiry performance demonstrated during the students' learning in the environment.

We developed detailed scoring rubrics to score the students' responses. In general, for the conceptual items, one point was given for an appropriate response and zero for an inappropriate one. For the inquiry items, two points were given for a high quality response, one point for a moderate quality response, and zero for a low quality one. Two independent raters coded all the tests, and the inter-coder agreement reached 95%. Inconsistent codes were discussed and resolved. Each individual student had six scores, namely, pretest knowledge, pretest inquiry, embedded assessment knowledge, embedded assessment inquiry, posttest knowledge, and posttest inquiry. We employed multiple regressions to conduct path analyses to test the relationships among these variables (Foster, Barkus and Yavorsky, 2006).

4. Results

We summarized the path analysis results in Figure 3 for the posttest knowledge scores and in Figure 4 for the posttest inquiry scores. Figure 3 shows a significant path from the students' prior inquiry skills to their knowledge demonstrated during class, then to the inquiry skills demonstrated during class, and finally to their knowledge demonstrated in the posttests. The path shows direct significant effects from one variable to another among the four variables. The students' prior knowledge did not have any significant effect. The students' prior inquiry skills had an indirect effect on their inquiry skills during class, and the knowledge learned during class also had an indirect effect on the knowledge demonstrated after class. Figure 4 shows a similar path pattern for the inquiry skills demonstrated in the posttests. The only difference is that the students' prior inquiry skills had a direct effect on their inquiry performance on the posttest.

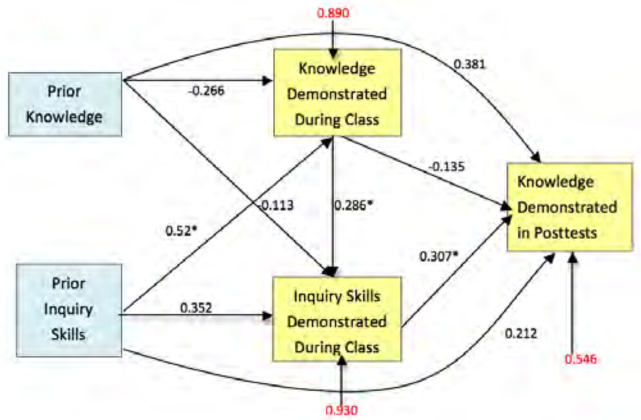

Figure 3. A path diagram for conceptual knowledge demonstrated in the posttests

Table 1: Total significant effects for the path shown in Figure 3

	Prior Knowledge	Prior Inquiry	During Class Knowledge	During Class Inquiry
Posttest Knowledge	0	0.045	0.087	0.307

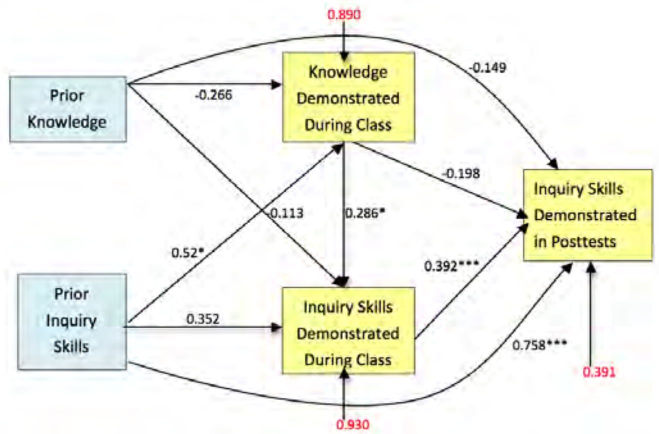

Figure 4. A path diagram for inquiry skills demonstrated in the posttests

Table 2: Total significant effects for the path shown in Figure 4

	Prior Knowledge	Prior Inquiry	During Class Knowledge	During Class Inquiry
Posttest Inquiry	0	0.816	0.112	0.392

We summarized the total effects on the posttest knowledge performance in Table 1, and on the posttest inquiry performance in Table 2. Table 1 indicates that the students' inquiry during class had the strongest effect on their posttest knowledge performance, with their knowledge during class having an effect in between, and their prior inquiry skills having the least effect. For Table 2, the inquiry skills that the students possessed before class had the strongest effect on their inquiry performance on the posttest, with the middle effect of their inquiry developed during class, and least effect on their knowledge gained during class.

The red numbers in Figures 3 and 4 are the calculated error values for the dependent variables. These error values indicate variances not explained by the model. For both the knowledge and inquiry skills demonstrated during class, the error values are high, indicating that there are other variables not included in the model that might be better than the students' prior knowledge and prior inquiry skills at accounting for their knowledge and inquiry demonstrated during class. We conjecture that the other variables include guidance and scaffolding from the teacher and learning environment. Qualitative analyses can verify this conjecture, but this is beyond the scope of this paper.

5. Concluding Remarks

Compared to SEM, multiple regression models for path analyses are suitable for studies with smaller sample sizes to explore possible relationships for further study. Through such techniques we found that compared to their prior knowledge, students' inquiry skills are more important in terms of predicting posttest performance on both the conceptual and inquiry measures. Nevertheless, knowledge, especially the knowledge learned during class, still has effects on students conducting adequate inquiries. From a broader viewpoint, the development of knowledge and inquiry skills may be interwoven (Bao et al., 2006). When examining on a finer scale, the paths in the two diagrams follow a "Z" shape, starting from personal inquiry skills. Such a result has implications for the call for learning environments that emphasize the progressive development of inquiry skills. However, the results reported here are specific to the context of this study, including the simulation-based inquiry environment in which semi-structured curricular scaffolds and teacher guidance are provided to support student inquiry with the simulations (for details of the curriculum design, see Hsu, Chang, Fang and Wu, in press). Future studies can explore whether there are different paths when engaging students in other inquiry learning environments with less or more scaffolding or guidance.

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