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Learning differences and eye fixation patterns in virtual and physical science laboratories

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A B S T R A C T

This project analyzed high school students' performance and eye movement while learning in a simulation-based laboratory (SBL) and a microcomputer-based laboratory (MBL). Although the SBL and the MBL both used computers to collect, graph, and analyze data, the MBL involved manual manipulation of concrete materials, whereas the SBL displayed everything on a monitor. Fifty senior high school students at three urban public high schools in Taipei were randomly assigned to the MBL and SBL settings. The participants conducted the Boyle's Law experiment with an accompanying worksheet and completed pre- and post-conceptual tests. FaceLAB and ASL MobileEye were used to record each participant's eye movements in the SBL and MBL settings, respectively. The results showed that lower achievers improved significantly from the pre-to post-conceptual tests. The SBL group tended to carry out more experiments. Moreover, the MBL group's performance on the worksheet was moderately correlated with their post-test. However, this correlation was not found for the SBL group. Furthermore, at the beginning of the laboratories, the SBL group had a higher percentage of fixations with longer fixation duration, which implies more attention to and deeper cognitive processing of the equipment and running experiments, while the MBL group focused on the worksheet. This study concludes that, for e-learning like SBLs, students tend to start off doing an experiment, and then think about the questions on the worksheets, whereas for physical laboratories like MBLs, they tend to think before doing.

1. Introduction

This project investigates high school students' conceptual learning and eye fixation patterns in physical and virtual laboratories. In this study, we use the term physical laboratory to refer to a microcomputer-based laboratory (MBL) in which students manipulate concrete objects with their hands, and collect and analyze data using sensors and handheld computers. On the other hand, virtual laboratory refers to a simulation-based laboratory (SBL) in which students manipulate objects and variables to conduct experiments on desktop computers. MBLs and SBLs, two alternatives to traditional laboratories, are technology-enhanced. Both support quick data acquisition and real-time graphing. Multiple trials can be carried out within a certain period of time. Moreover, more time is saved for higher-order cognitive tasks such as designing experiments, justifying decisions, evaluating experimental results, interpreting data and graphs, and building models. Therefore, they make authentic experimentation feasible in a typical class period. MBLs and SBLs are similar in many respects. The major difference is the interaction with concrete versus virtual materials.

In an MBL, students measure properties such as temperature, light, force, etc. with probes. The probes output data in voltages. With analog-to-digital converters, students can record and analyze data on computers or handheld devices such as tablets and smart phones. Previous studies have revealed that MBLs are more effective in terms of promoting conceptual understanding than traditional laboratories (Brassell, 1987; Nakhleh & Krajcik, 1994; Nicolaou, Nicolaidou, Zacharia, & Constantinou, 2007). MBLs have several features that promote

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learning. The first distinguishing feature of MBLs is that they graph data instantaneously (Nicolaou et al., 2007; Pierri, Karatrantou, & Panagiotakopoulos, 2008). The handheld device can display the graph in real time. Real-time graphing lessens short term memory loading (Brassell, 1987) and enhances students' ability to interpret graphs (Bisdikian & Psillos, 2002; Linn & Songer, 1991). As a result, students can better link phenomena to scientific theories (Bisdikian & Psillos, 2002). Furthermore, MBLs save an extensive amount of time spent on tedious work such as data recording and organizing, allowing the students to repeat the experiments (Russell, Lucas, & McRobbie, 2004) and giving them time (Hucke & Fischer, 2002) and cognitive resources for abstract cognitive thinking. Consequently, the students' ability to understand scientific concepts is enhanced.

An MBL involves the hands-on feature of traditional laboratories, i.e., physical manipulation of equipment, and also some of the strengths of SBLs. When a traditional laboratory is replaced with an MBL, the number of experiments conducted during the same period of time is greatly enhanced and would be close to the number of experiments done in an SBL (Chen, 2014). Moreover, the real-time display of graphs also brings MBLs closer to the dynamic visualization of simulations.

In short, the replacement of traditional laboratories with MBLs in the present study makes the experimental (virtual laboratory) and control (physical laboratory) groups comparable in terms of quick data acquisition, dynamic visualization of data, and error rates. With these extraneous variables controlled, this experimental design provides robust evidence of the efficiency of the SBL and physical manipulatives. Our previous study revealed that they are equally effective in terms of conceptual learning (Chen, 2014). The present study goes further in examining students' attention and cognitive processing in these environments.

This study pays particular attention to students' eye fixation patterns while conducting the Boyle's Law experiment. An often quoted proverb regarding learning is that “I hear and I forget, I see and I remember, I do and I understand.” Visual attention is an important issue in learning. According to the premotor theory of attention (Rizzolatti, Riggio, Dascola, & Umiltá, 1987), mechanisms for directing attention to a location might be similar to mechanisms for preparing an eye movement. Experiments have also found overlapping neural systems for covert spatial attention with overt oculomotor shifts (Nobre, Gitelman, Dias, & Mesulam, 2000). Thus, this project detects learners' eye movements to study their attention. The results will contribute to the understanding of learning in laboratories, and the tradeoffs between the two types of laboratories. This knowledge will help science educators to develop laboratory curricula and integrate physical and virtual laboratories.

2. Students' learning in virtual and physical laboratories

2.1. Theoretical base

Researchers have proposed different theories to explain learning in virtual and physical laboratories. On the one hand, SBLs can involve multiple representations, especially dynamic visualizations and analogies for abstract and unobservable phenomena, which help learners integrate theories, symbolic equations, graphs, processes, and phenomena (Olympiou, Zacharias, & de Jong, 2013; Ploetzner, Lippitsch, Galmbacher, Heuer, & Scherrer, 2009; Trey & Khan, 2008; Trindade, Fiolhais, & Almeida, 2002). Learners receive rich information and support. Furthermore, they can make clear observations (Renken & Nunez, 2013). For example, time and space may be rescaled for macro- and micro-phenomena; graphs can be shown in real time to link phenomena to scientific theories; and data are clean and matched with scientific theories. Clear observations help to expose cognitive conflicts between the observed evidence and learners' alternative conceptions, and thus promote conceptual change.

On the other hand, the grounded/embodied cognition theory suggests that physical laboratories enhance learning. The theory considers cognition as interactive, embodied, and embedded (Calvo & Gomila, 2008). “Cognition depends upon the kind of bodily experiences we have as we interact through our perceptual and motor systems with the environment” (Bivall, Ainsworth, & Tibell, 2011, p. 702). Thought and knowledge emerge from physical and social interactions between learners and the surrounding environment. Consequently, physical manipulatives are important for laboratory learning.

The abovementioned theories support SBLs and physical laboratories from different perspectives of learning context/environment and information delivery (multiple representations versus multiple modalities). They provide a basis for understanding learning outcomes and processes in SBLs and physical laboratories.

2.2. Empirical evidence

A few researchers have succeeded in comparing virtual and physical laboratories under conscious control of extraneous variables. Most studies reveal that they are equally effective in terms of learning concepts, learning the control of variables, and fostering confidence (de Jong, Linn, & Zacharia, 2013). For example, Klahr and colleagues have conducted a series of experiments on this issue. Their studies show no statistical difference in knowledge of controlling variables and causal factors and confidence between students manipulating physical materials and computer simulations. Triona and Klahr (2003) compared 46 fourth and fifth graders manipulating physical materials with an equal number of students working on computer simulations. Both groups received the same instruction and practiced the control of variables strategy to design and interpret simple unconfounded experiments. The appearance of the materials was featured as closely as possible in both groups. The two groups were not significantly different in any of their test scores, including for their pre- and post-test knowledge of the control of variables as well as for a far transfer test given 7 months later. The results suggest that a well-designed virtual environment that preserves the essential experience of manipulation and experimentation is as effective as hands-on manipulation of physical materials.

Next, Klahr, Triona, and Williams (2007) tested a different type of instruction and a different type of knowledge with an older age group (7th and 8th grades). Instead of focusing on domain-general knowledge of controlling variables, domain-specific knowledge about features of good running cars was spotlighted. The visual and tactile information presented in the virtual condition was substantially different from the physical condition; cartoon-like cars, rather than photographs or video images, were used. The pre-/post-test of knowledge of causal factors, the ability to design optimal cars, and confidence in their knowledge revealed that the students learned equally well using physical