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Comparing the Influence of Physical and Virtual Manipulatives in the Context of the Physics by Inquiry Curriculum: The Case of Undergraduate Students' Conceptual Understanding of Heat and Temperature

Context of the study. The current literature on reform in science education has reopened the debate on the role and practice of laboratory experimentation in science teaching and learning. One reason is the rapid growth of computer-based virtual manipulatives and their implications for teaching, learning, and research. Research results suggest that laboratory experimentation, as commonly experienced by the use of physical manipulatives, can be redefined and restructured to include virtual manipulatives.

The purpose of this study was to investigate whether the two modes of experimentation are equally conducive to physics learning, while controlling for the method of instruction, curricular materials, and the resource capabilities of the two modes. We made an explicit effort to design a study that controls for all variables that might affect learning outcomes, which is an important limitation of prior studies. The manipulatives were selected so that both could offer participants the same capabilities for experimentation.

Research questions. Are the two modes of experimentation equally conducive to conceptual understanding in physics? Is manipulation, rather than physicality, the important contributor to learning?

Theoretical framework. A social constructivist framework, which entails the construction of knowledge within a community of learners in the classroom, is used in the design of both the experiment and supporting materials (first two sections of the *Heat and Temperature* modules of the *Physics by Inquiry* curriculum).

Methodology. The participants of the study are 68 undergraduate students (15 male, 53 female) in an introductory physics course for preservice elementary school teachers at a university in Cyprus. The participants were randomly separated into control (n = 34) and experimental (n = 34) groups. None of the participants had previously taken college physics. The students in both groups were randomly assigned to subgroups whenever possible.

The physical manipulatives involved the use of real instruments in a conventional physics laboratory. During the experiments, feedback is available to students through the behavior of the actual system and through the instruments that are used to monitor the experimental setup.

The virtual manipulatives involved the use of the virtual lab THERMOLAB because of its fidelity and the fact that it retains the features and interactions of *Heat and Temperature* like the physical manipulatives. In this open-ended environment students in the experimental group can design and conduct any experiment discussed in the module of *Heat and Temperature* by employing the “same” material as the ones used by the control group where real instruments were used. The amount of feedback is analogous to what is routinely available to students experimenting with physical manipulatives.

A pre–post comparison study design was used. The two control groups worked in the same laboratory environment, which has both conventional equipment and a computer network at the periphery. The duration of the study was about two months. Students met once a week for 90 minutes. The time on task was the same for both groups. In particular, both groups spent the same amount of time on a brief introduction that familiarized the students before engaging in the study’s conditions. We controlled for the time on task required for students using both kinds of manipulatives. In this way, the participants of the experimental group did not have the convenience that the virtual experiments would otherwise have provided. It has been found that the time on task is one of the variables that influences the learning process and outcomes of a learning activity in favor of virtual manipulatives, because a virtual manipulative activity can be experienced by students more times in a given time period than a physical manipulative

Conceptual tests were administered to assess the students’ understanding of concepts related to temperature and changes in temperature. A temperature and change in temperature test was administered before and after instruction. In addition, before and after completing each section two more tests were administered: a temperature test and a changes in temperature test.

The data analysis involved both quantitative and qualitative procedures. The quantitative analysis involved paired sample t-tests for the comparison of the pretest to the posttest scores on the three tests for each group separately, and one-way ANCOVA for the comparison of the posttest scores of the two groups on each test. The qualitative data analysis focused on identifying and classifying students’ scientifically accepted and nonscientifically accepted conceptions. The analysis followed the procedures of phenomenography, which is used to identify students’ qualitatively different, hierarchically related conceptions of learning.

To ensure objective assessment, the tests were coded and scored anonymously. Internal reliability data were also collected for both research questions. Two independent coders reviewed about 25% of the data. The reliability measures (Cohen's kappa) for scoring of the T&CT test (pre and post) and tests 1 and 2 (pre and post), were 0.89, 0.88, and 0.9, respectively. The reliability measure, proportion of agreement, for the qualitative analysis is calculated as the agreement coefficient for the categories of students' conceptions was 0.88. Disagreements were discussed after the reliability analysis and were resolved by consensus.

Findings and conclusions. The paired-samples t-test procedure indicated that the mean scores for both groups on each of the posttests were statistically higher, at the *p 0.001 level, than the corresponding mean scores on the pretests. These scores show that both conditions improved undergraduate students' conceptual understanding of temperature and changes in temperature. The one way ANCOVA procedure did not reveal any significant differences between the posttest scores of the two groups for the tests of the study. This finding suggests that the use of physical and virtual manipulatives were equally effective in promoting the students' understanding of concepts concerning temperature and changes in temperature.*

The phenomenographic analysis revealed that the two groups shared mostly the same conceptions concerning changes in temperature, either scientifically accepted or not, both before and after the teaching intervention.

Additionally, most of the participants of both groups shifted from nonscientifically accepted to scientifically accepted conceptions after the study. Both groups were found to have the highest prevalence for scientifically accepted and lower prevalence for nonscientifically accepted, with similar shifts in their frequency. Moreover, the two groups shared the same most prevalent nonscientifically accepted conceptions. These findings indicate that the use of physical and virtual manipulatives had the same effect on the students' understanding of concepts concerning changes in temperature, namely, on the transition from nonscientifically accepted to scientifically accepted as well as on the nature of conceptions concerning changes in temperature after the study.

This study revealed that both virtual and physical manipulatives can be effective in developing conceptual understanding. This finding challenges commonly held assumptions about laboratory work in the physics classroom and calls for a redefinition and restructuring of experimentation to include both physical and virtual manipulatives. This call for change creates the need for understanding how both modes of experimentation should be integrated in activity sequences for physics teaching and learning.

Reflective Essay (theme: Lessons Learned) by Zacharias Zacharia

The findings of this study leave open the question about the conditions under which the use of physical or virtual manipulatives in science experimentation may be preferable. Findings of recent empirical studies that involved comparisons between virtual and physical manipulatives, although limited, have revealed instances where the use of virtual manipulatives would appear to be more beneficial to science learning than the use of physical manipulatives and vice versa. If the use of one type of manipulative brings expanded or improved opportunities for student learning in the course of conducting experiments, that manipulative should be preferred over the other. For example, only the “messy” interactions with physical manipulatives teach students about the underlying complexity of collecting scientific evidence (for example, measurement errors) and give them a more grounded perspective on the limitations of specific virtual environments. In contrast, virtual manipulative interactions are the only ones that provide students with opportunities to manipulate conceptual objects (objects that have no perceptual fidelity) or depict and study phenomena of very large or very small temporal and physical dimensions (such as those of interest in astronomy or molecular dynamics).

Much promise lies in efforts to combine physical and virtual manipulatives so as to optimize the effectiveness of individual activities in a teaching learning sequence. Thus, one of the lessons we learned is that it is essential to expand the empirical base through similar research in an attempt to develop a framework for integrating physical and virtual manipulatives within science and engineering learning environments. There are a number of questions that should be answered before formulating this framework in detail. For instance, “In what types of activities should PM be preferred over VM and vice versa?”, “What parameters can be employed to formulate optimal combinations of PM and VM rather than using them alone?”, “If combining PM and VM appears to be more promising and effective than using them alone, how do blended combinations compare with sequential ones?”.

(Structured summary abstracted from the article by the Managing Editor)

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