THE EFFECT OF REAL AND VIRTUAL LABORATORY EXPERIMENTATION ON STUDENTS' UNDERSTANDING OF ELECTRIC CIRCUITS

Zacharias Zacharia, Maria Evagorou

ABSTRACT
This study compared the effect of Virtual Laboratory Experimentation (VLE) - use of virtual apparatus and material to conduct an experiment on a computer - and Real Laboratory Experimentation (RLE) - use of real apparatus and material to conduct an experiment in a laboratory - on undergraduate student teachers' understanding of electric circuits. A pre-post comparison study design was used for this purpose that involved an experimental (45 students) and a control group (43 students). Both groups used the same instructional method (inquiry) and instructional material (Physics by Inquiry-McDermott, 1996). However, participants in the control group used RLE to conduct the study's experiments in a physics laboratory, whereas, participants in the experimental group used VLE to conduct the same experiments on a computer. Conceptual tests were administered to assess students' understanding of electric circuits both before and after the study. Results indicated that the use of VLE improved students' achievement and understanding more than RLE

KEYWORDS
electric circuits, experimentation, inquiry, simulations, virtual laboratory

INTRODUCTION

Students understanding of various science topics has been the focus of many studies in psychology and science education in the past (Borges & Gilbert, 1999; Driver, 1996; McDermott, 1984; Van Heuvelen, 1991). It has been repeatedly shown that students, even pre-service teachers, share a number of alternative conceptions that differ from the scientifically accepted conceptions (Bowden et al., 1992; Rosenquist & McDermott, 1987; Sneider and Ohadi, 1998; Tytler 1998). Posner *et al.* (1982) point out that students' ideas about how the world operates are strongly held because their conceptual knowledge has been constructed over many years of experience in the everyday world. Consequently, an effective instructional approach should consider students' ideas about the world and promote conceptual change (Roth & Lucas, 1997). Kalman et al. (1999) state that conceptual change requires from the learners to critically examine their conceptions of the natural world taking in mind specific evidence. According to McDermott (1990), conceptual change requires active involvement of the learners since learning, as stated by Tobin (1990), is an active, interpretive and iterative process in which students construct their ideas based on a series of experiences. One learning method that has proven to support learner's active involvement in science education is laboratory experimentation.

Laboratory experimentation shifts from teacher directed learning to student directed learning, thus allowing students to interact with materials and models, and understand the natural world (Baird, 1990; Hofstein & Lunetta, 2004; NRC, 1996). A lot of researchers (e.g., Bybee, 2000; Lunetta, 1998) emphasize on the importance of rethinking the role and practice of laboratory work in science teaching because it has the potential to enhance conceptual understanding.

There are two distinct examples of laboratory experimentation:

- Real Laboratory Experimentation (RLE): the use of real apparatus and material to conduct an experiment in a laboratory, and
- Virtual Laboratory Experimentation (VLE): the use of virtual apparatus and material to conduct an experiment on a computer (e.g., experimentation provided through the use of interactive simulations).

Both RLE and VLE provide the opportunity to the learners to interact with materials and models, and check hypothesis (Hofstein & Lunetta, 2004; Tao & Gunstone, 1999). The learners can observe and interpretate the phenomena as presented in the virtual or real experiments, compare their interpretations with their conceptions/ideas and resolve possible disagreements between their ideas and the ones presented in the experiments. The combination of these possibilities makes VLE and/or RLE promising learning tools for promoting conceptual understanding.

Despite the plethora of research focusing on the evaluation of the impact of RLE and VLE on conceptual understanding (Hofstein & Lunetta, 2004; Zacharia and Anderson, 2003), not many research studies exist that compare the effect of VLE and RLE on conceptual understanding. The purpose of this study was to compare the effect of RLE and VLE on students understanding of Kirchoff's second rule.

RESEARCH METHODS

Sample

The participants of the study were 88 undergraduate student teachers (henceforth called students), enrolled in an introductory course in physics that was based upon the *Physics by Inquiry* curriculum (McDermott and The Physics Education Group, 1996). The course took place at a university in Cyprus.

The participants were randomly separated into two groups, namely, the experimental or VLE group (45 students) and the control or RLE group (43 groups). None of the participants had taken college physics prior to the study.

In addition, the students in both the experimental and control groups were randomly assigned to subgroups (of three) as suggested by the curriculum of the study. This particular curriculum is grounded upon a social constructivist framework (e.g., Cole, 1996; Wells, 1999) that entails the construction of knowledge within a community of learners in their classroom (Penner, Lehrer, and Schuble, 1998).

Even though all participants were computer literate, special attention was given to familiarizing the students in the experimental group with the Virtual Labs Electricity software. Similarly, the students in the control group were given time to familiarize with laboratory materials and apparatuses.

The curriculum materials: Physics by Inquiry

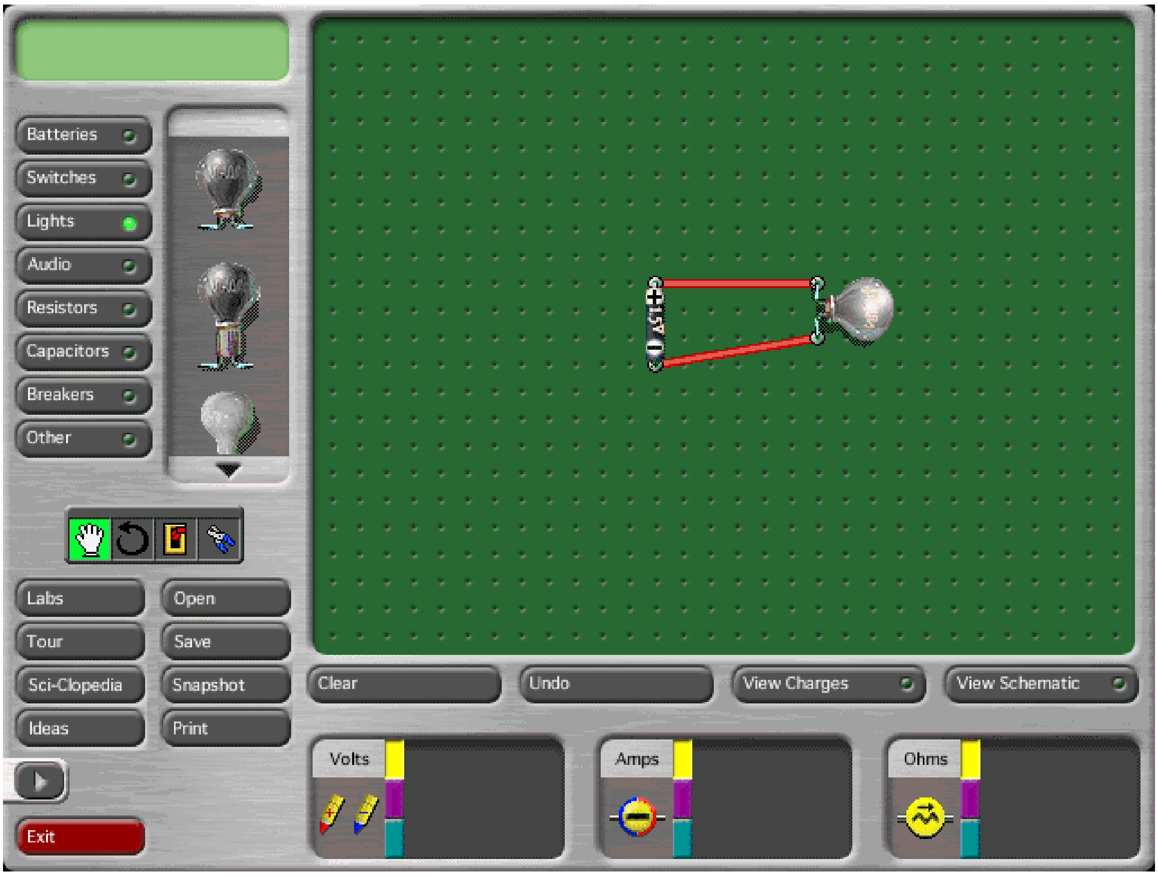
Both groups used the same instructional method (inquiry) and curriculum on electric circuits (Kirchoff's second rule) - (McDermott and The Physics Education Group, 1996, p. 382) - for the purposes of this study. The module of *Electric Circuits* encourages students to make the necessary mental commitment by guiding them through the process of constructing a conceptual model for an electric circuit from "direct hands-on" experience with batteries and bulbs. The activities (exercises and experiments) are carefully sequenced and validated through research as a process of developing conceptual understanding (McDermott and Shaffer, 1992; Shaffer and McDermott, 1992).

The selection of the *Physics by Inquiry* curriculum was based on four reasons: (a) it was developed through research (McDermott and Shaffer, 1992; Shaffer and McDermott, 1992), (b) it has been shown, when being implemented through the use of RLE, to be an effective approach to science learning for both pre-service and in-service teachers (McDermott, 1992; Zacharia and Anderson, 2003), (c) it is reasonable to assume that curriculum materials that have been shown to be effective in promoting conceptual understanding through RLE experiences will also tend to be appropriate for individuals using

VLE, especially considering the argument that it is manipulation, rather than physicality, as such, that may be the important aspect of instruction, and (d) the basic precepts of cognitive science suggest that what is important in science learning is the presence of interactive engagement (Resnick, 1998; Triona and Klahr, 2003), which is at the core of the *Physics by Inquiry* curriculum.

Experimental Design

A pre-post comparison study design was used that involved a different method of experimentation for the experimental and control group. Specifically, the method of experimentation used by the control group involved the use of real apparatus and material in a conventional laboratory environment, whereas, the method of experimentation used by the experimental group involved the use of virtual apparatus and material to conduct the study's experiments on a computer (see picture 1).

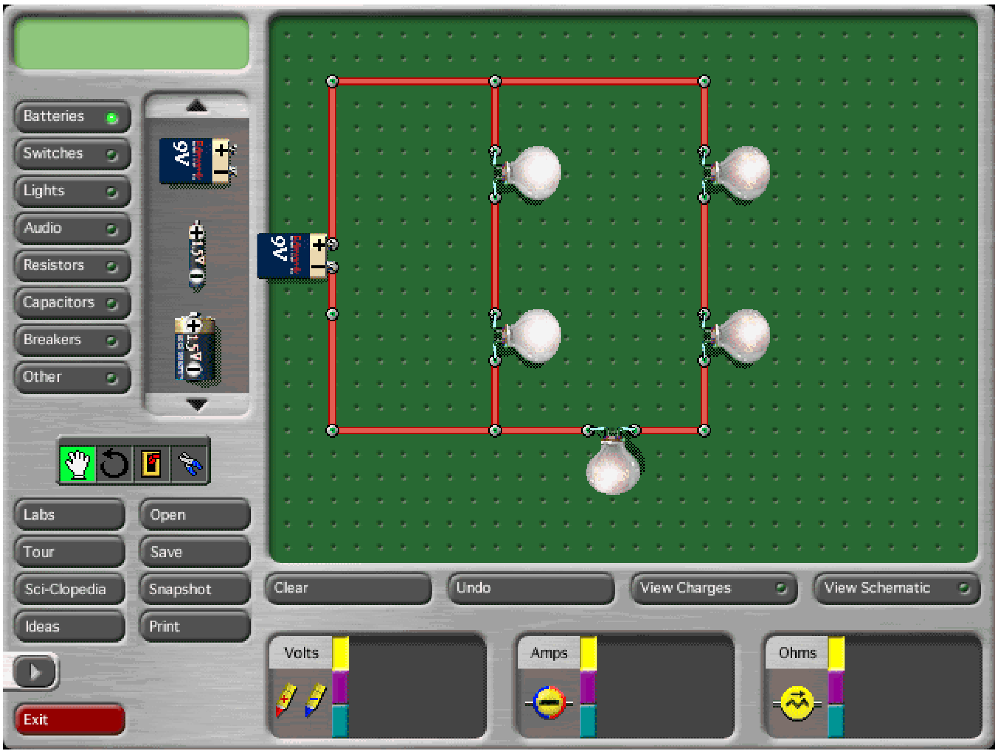


Picture 1. An example of a (virtual) circuit

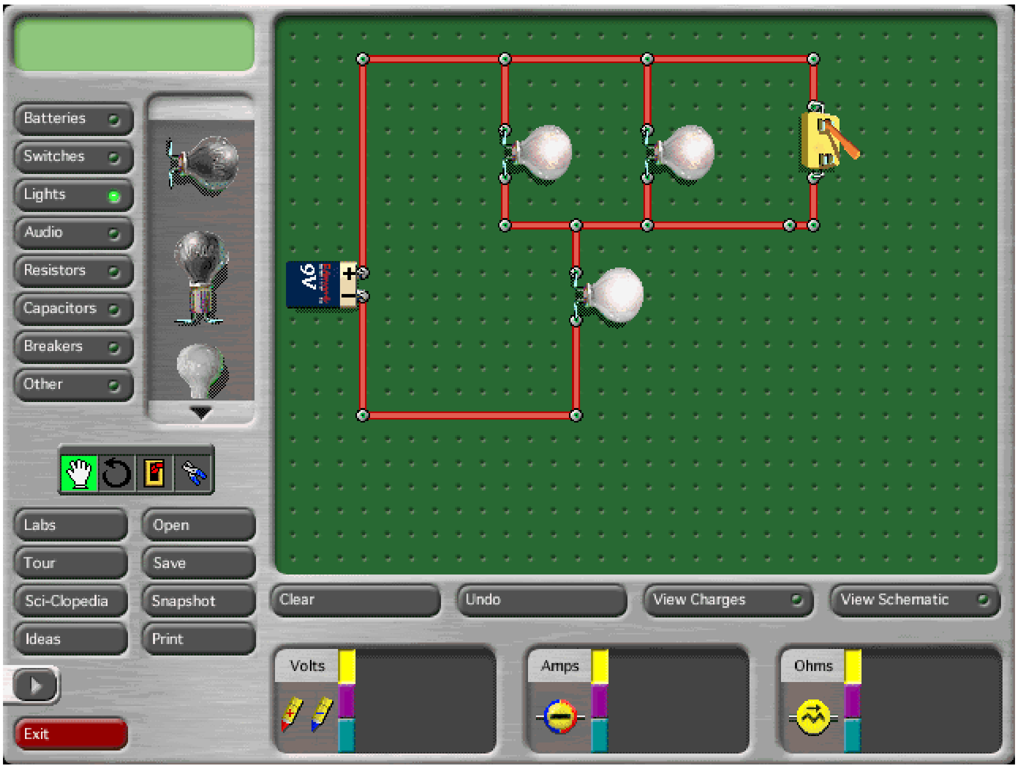
In this study, the software *Virtual Labs Electricity* (Riverdeep Interactive Learning, 2003) was used for conducting the study's experiments on a computer (see picture 2). The software environment is user friendly and does not require any specialized computer skills.

Picture 2. The environment of Virtual Labs Electricity

In the open-ended environment of *Virtual Labs Electricity*, students were able to design and test any DC circuit mentioned in Chapter 8 (McDermott and The Physics Education Group, 1996, p. 382) by employing the "same" circuit parts as the ones used by the RLE group (see pictures 3 and 4).



Picture 3. Circuit created by a participant of the study



Picture 4. Circuit created by a participant of the study

The duration of the research intervention was two weeks (4 meetings, 90 minutes each). Data were collected both before and after the study.

Data collection
A Conceptual test was administered to assess students' understanding of Kirchoff's second rule both before and after the study (see Table 1).

Table 1. The experimental design of the study.

	Data collection before the study	**Research Intervention**	**Data collection after the study**
Experimental Group (VLE)	Pre-test (McDermott and Shaffer, 1992; Shaffer and McDermott, 1992)	○ Chapter 8 (McDermott and The Physics Education Group, 1996). ○ Use of virtual apparatus and material to conduct an experiment on a computer.	Post-test (McDermott and Shaffer, 1992; Shaffer and McDermott, 1992)
Control Group (RLE)	Pre-test (McDermott and Shaffer, 1992; Shaffer and McDermott, 1992)	○ Chapter 8 (McDermott and The Physics Education Group, 1996). ○ Use of real apparatus and material to conduct an experiment in a laboratory.	Post-test (McDermott and Shaffer, 1992; Shaffer and McDermott, 1992)

The test was developed and used in previous research studies by the Physics Education Group of the University of Washington (McDermott and Shaffer, 1992; Shaffer and McDermott, 1992). The test contained open-ended items that asked conceptual questions all of which required explanations of reasoning. Each item of the test was scored separately; however, a total correct score was derived from each participant's test and used in the analyses.

Data Analysis

The data analysis involved both qualitative and quantitative procedures. However, only the results of the quantitative analysis are reported in this paper.

The quantitative analysis involved the use of an independent samples t-test and a paired samples t-test. The independent samples t-test was applied to determine whether one of the two groups (VLE and RLE) had significantly different pre- and post-test scores than the other group, whereas, the paired samples t-test was used to check if the pre- and post-test scores of each group (VLE or RLE) were significantly different.

To ensure objective assessment, the tests (pre- and post-) were coded and scored anonymously. Internal reliability data were also collected. Two independent coders reviewed 25% of the data. The reliability measure was 0.91.

RESULTS

The quantitative analysis revealed that: (a) the VLE and RLE group increased their average scores (see Table 2), and (b) the VLE group had significantly higher post-test scores than the RLE group.

Table 2. The VLE and RLE average scores both before and after the study

	Pre-test (Highest score=100)	**Post test** (Highest score=100)
Experimental Group (VLE)	43.51	68.31
Control Group (RLE)	40.75	52.21

Specifically, the use of paired samples t-tests revealed that both the experimental and control group had significantly higher post-test scores than pre-test scores ($p < 0.001$ for both groups). However, the post-test scores of the VLE group were higher than the post-test scores of the RLE group.

Furthermore, independent samples t-test revealed that the pre-test scores of the two groups were not different prior to instruction ($p = 0.85$), whereas, the post-test scores of the VLE group were significantly higher than the post-test scores of the RLE group ($p < 0.05$).

DISCUSSION

Much research has been done to investigate exactly what kind of ideas, scientifically accepted or not, are developed by students using RLE and/or VLE in physics classes. These findings are particularly important, because designing a physics curriculum requires an understanding of the particular state of the student's knowledge (Dykstra et al., 1992). However, very little research has been done on how VLE or a combination or VLE and RLE can be integrated in a physics curriculum.

DeBoer (1991) has argued that the processes of research and curriculum development are inextricably intertwined. Thus, curriculum development raises issues that call for research, both with respect to student conceptual understanding and the efficacy of instructional methods and materials. Correspondingly, the results of research have implications for curriculum development, both in terms of what to teach and how to teach it.

The present study aimed to clarify the effects that RLE and/or VLE have on students' conceptual understanding of Kirchoff's second rule. The comparisons between the experimental and the control groups showed that the use of VLE or RLE when grounded in the framework of inquiry can help students gain better understanding of concepts related to electric circuits. However, the fact that the use of VLE enhanced students' conceptual understanding of Kirchoff's second rule more than the use of RLE shows that VLE is a tool with great potential that can have a positive effect on students' conceptual understanding.

The study was done in the natural setting of a classroom and included the RLE and VLE within a normal course of study in physics, thus adding additional validity to the conclusions that use of VLE can enhance physics learning when properly integrated within a substantial physics curriculum emphasizing conceptual understandings.

VLE should, by no means, replace RLE or any activity aimed at experiencing and investigating the real phenomena. Nevertheless, it seems that VLE can enhance students' conceptual understanding and, therefore, it should be regarded as a tool with great potential and not as a "second best" to RLE (Ronen and Eliahu, 2000).

CONCLUSION AND IMPLICATIONS

Steinberg (2000) has stated that, if we ignore the critical role of computers in science and engineering, we would be doing a disservice to students. VLE seem capable of playing an important role in cognitive development and concept learning, and therefore, physics curriculum and instruction should definitely include them along with RLE. However, the process of integrating VLE into physics curricula requires further research. Neglecting this research may result in missing the desired positive effects of the VLE on students' knowledge.

Studies in this domain are particularly important because they could, ultimately, answer potential questions on whether computer-based physics courses could be offered through the World Wide Web for long distance learning and how these courses could be more effective.

REFERENCES

Baird, J. R. (1990). Metacognition, purposeful enquiry and conceptual change. In E. Hegarty-Hazel (Eds.), *The students laboratory and the science curriculum.* London: Routledge.

Bybee, R. (2000). Teaching science as inquiry. In J. Minstrel & E.H. Van Zee (Eds.), *Inquiring into inquiry learning and teaching in science*. Washington DC: AAAS.

Cole, M. (1996). *Culture in mind.* Cambridge, MA: Harvard University Press.

DeBoer, G. (1991). *A History of Ideas in Science Education*. NY: Teachers College Press.

Dykstra, D. I., Boyle, F. and Monarch, A. (1992), Studying conceptual change in learning physics, *Physics Education*, 76, 615–652.

Driver, R. (1996). *Young people's images of science*. Bristol: Open Press University.

Hofstein, A. & Lunetta, V.N. (2004), The laboratory in science education: Foundations for the Twenty-First Century, *Science Education*, 88, 28-54.

Kalman, C. S., Morris, S., Cottin, C. and Gordon, R. (1999), Promoting conceptual change using collaborative groups in quantitative gateway courses, *American Journal of Physics*, 67, 45–51.

McDermott, L. C. (1984), Research on conceptual understanding in mechanics, *Physics Today,* 37, 24–32.

McDermott, Lillian (1990), Milikan Lecture 1990: "What we teach and what is learned - Closing the gap," *American Journal of Physics*, 59, 301-315.

McDermott, L. C. (1992). A perspective on teacher preparation in physics and other sciences: The need for special science courses for teachers. *American Journal of Physics*, 58, 734-742.

McDermott, L.C. and Shaffer, P. (1992), Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding, *American Journal of Physics*, 60, 994-1002.

McDermott, L. C. and The Physics Education Group (1996). *Physics by Inquiry*. New York: Wiley.

Penner, D. E., Lehrer, R., & Schauble, L. (1998). From physical models to biomechanics: A design based modeling approach. *The Journal of the Learning Sciences*, 7, 429-449.

Piaget, J. (1985), *The Equilibration of Cognitive Structure*. Chicago: University of Chicago.

Posner, G., Strike, K., Hewson, P. and Gertzog, W. (1982), Accommodation of a scientific conception: Toward a theory of conceptual change, *Science Education*, 66, 211–227.

Redish, E. F. and Steinberg, R. N. (1999), Teaching physics: Figuring out what works, *Physics Today,* 52, 24–30.

Resnick, M. (1998). Technologies for lifelong kindergarten. *Educational Technology Research and Development*, 46, 43–55.

Riverdeep Interactive Learning (2003). *Virtual Labs Electricity*.
http://www.riverdeep.net/product/virtual_labs/index.jhtml

Ronen, M. and Eliahu, M. (2000). Simulation – a bridge between theory and reality: the case of electric circuits. *Journal of Computer Assisted Learning*, 16, 14-26.

Rosenquist, M. and McDermott, L. C. (1987), A conceptual approach to teaching kinematics, *American Journal of Physics*, 55, 407–415.

Roth, W. M. and Lucas, K. (1997), From 'Truth' to 'Invented Reality': A discourse analysis of high school physics students' talk about scientific knowledge, *Journal of Research in Science Teaching*, 34, 145–179.

Shaffer, P. and McDermott, L. (1992). Research as a guide for curriculum development: An example from introductory electricity, Part II: Design of instructional strategies. *American Journal of Physics*, 60, 1003-1013.

Sneider, C. J. and Ohadi, M. M. (1998). Unraveling students' misconceptions about the earth's shape and gravity. *Science Education*, 82, 265-284.

Steinberg, R. N. (2000). Computers in teaching science: To simulate or not to simulate? *Physics Education Research, American Journal of Physics Supplement*, 68, 16-24.

Tao, P. and Gunstone, R. (1999), The process of conceptual change in force and motion during computer-supported physics instruction, *Journal of Research in Science Teaching*, 36, 859–882.

Tobin, K. G. (1990). Research on science laboratory activities. In pursuit of better questions and answers to improve learning. *School Science and Mathematics*, 90, 403-418.

Triona, L. and Klahr, D. (2003). Point and click or grab and heft: Comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments. *Cognition and Instruction*, 21, 149-173.

Tytler, R. (1998). Children's conceptions of air pressure: exploring the nature of conceptual change. *International Journal of Science Education*, 20, 929-958.

Van Heuvelen, A. (1997), Using interactive simulations to enhance conceptual development and problem solving skills, *AIP Conference Proceeding*, 399, 1119–1135.

Wells, G. (1999). *Dialogic inquiry. Towards a sociocultural practice and theory of education.* Cambridge: Cambridge University Press.

Zacharia, Z. and Anderson, O. R. (2003), The effects of an interactive computer-based simulations prior to performing a laboratory inquiry-based experiments on students' conceptual understanding of physics, *American Journal of Physics*, 71, 618-629.

Zacharias C. Zacharia
Lecturer
Learning in Science Group
Department of Educational Sciences
University of Cyprus
P. O. Box 20537
1678 Nicosia
Cyprus
Email: zach@ucy.ac.cy

Maria Evagorou
Graduate Student
Learning in Science Group
Department of Educational Sciences
University of Cyprus
P. O. Box 20537
1678 Nicosia
Cyprus
Email: sepgme4@ucy.ac.cy