USING PHYSICAL AND VIRTUAL MANIPULATIVES TO ENHANCE CONCEPTUAL UNDERSTANDING IN HEAT AND TEMPERATURE

Giorgos Olympiou, Zacharias C. Zacharia, Marios Papaevripidou, Constantinos P. Constantinou

ABSTRACT
The purpose of this study was to compare the effect of Physical Manipulatives (PM) and the combination of Physical Manupulatives with Virtual Manipulatives (VM) on pre-service teachers' understanding of scientific concepts in the domain of heat and temperature. A pre-post comparison study design was conducted that involved 62 undergraduate pre-service elementary school teachers enrolled in an introductory course in heat and temperature that was based upon the *Physics by Inquiry* curriculum (McDermott and The Physics Education Group, 1996). The participants were assigned to an experimental (EG, 34 students) and a control group (CG, 28 students). The CG used PM to conduct the experiments, whereas, the EG used a combination of PM and VM. Conceptual tests were administered to assess students' understanding before, during, and after the study The data analysis involved both quantitative and qualitative methods of analysis. The quantitative analysis showed that experimenting with the combination of PM and VM enhanced students' conceptual understanding more than experimenting with PM alone. The qualitative analysis revealed that the EG had a larger shift from not scientific accepted conceptions to scientific accepted conceptions concerning *changes in temperature*, *heat* and *heat transfer* than the CG.

KEYWORDS
Physical manipulatives, virtual manipulatives, conceptual understanding.

INTRODUCTION

During the past decade there have been many optimistic claims about the potential of virtual reality to enhance science laboratory teaching and learning (Barab et al., 2000). In fact, Virtual Manipulatives (VM), provided through interactive computer-based simulations, have proven to have a positive impact on students' evolving skills, attitudes, and conceptual understanding (de Jong & Njoo, 1992; Doerr, 1997; Finkelstein et al., 2005; Goldberg & Bendall, 1995; Goodyear, 1992; Gorsky & Finegold, 1992; Grayson, 1996a; Hewson, 1985; Hsu & Thomas, 2002; Huppert & Lazarowitz, 2002; Kaput, 1995; Lea et al., 1996; Mandinach & Cline, 1994; Ravenscroft, 2000; Shin *et al.*, 2003; Tao & Gunstone, 1999; Vreman-de Olde & de Jong, 2004; Zacharia, 2003, 2005, 2007; Zacharia & Anderson, 2003). In spite of these findings, some researchers have seriously questioned whether laboratory experimentation in science education, as we experienced it through Physical Manipulatives (PM), should be redefined and restructured to include VM, (Triona and Klahr, 2003; Zacharia, 2007). The ultimate goal is to take advantage of the potentials of both in order to maximize to the highest possible degree the effectiveness of experimentation (Zacharia, 2007).

Hofstein and Lunetta (2004) emphasized the value of learning through experimentation. They explained that experimentation, involving either PM or VM, shifts from teacher directed learning to student directed learning, thus allowing students to interact with materials and models in order to take control of their own learning in the search for understanding of the natural world. A lot of researchers today emphasize on the importance of rethinking the role and practice of experimentation in science teaching in promoting conceptual understanding (Bybee, 2000; Lunetta, 1998; NRC, 1999; Zacharia 2007). Research in science education (e.g., Zacharia, 2007) has shown that experimentation with PM or VM could enhance learner's conceptual understanding when learners are provided (a) with the opportunity to ask questions, suggest hypotheses, and design investigations - "minds-on as well as hands-on" (Gunstone & Champagne 1990; Gunstone 1991), and (b) with frequent opportunities for feedback, reflection, and modification of their ideas (Barron *et al.* 1998). In other words, both methods of experimentation could provide an exploratory learning environment, especially when grounded in inquiry, which allows the student to inquire into the event presented, to directly manipulate initial conditions (e.g., alter the values of variables), to initiate processes, to probe conditions and to observe the results of these actions (de Jong & Njoo 1992; Zacharia & Anderson 2003; Hofstein & Lunetta 2004). This unique combination of features enables students to interpret the underlying scientific conceptions of the phenomenon studied, compare them with their own conceptions, formulate and test hypotheses, reconcile any discrepancy between their ideas and the observations in the experiments, and discover and develop explanations for the mechanisms and processes underlying the physical phenomenon presented through the experimentation with PM or VM (Bybee 2000; Casey 1996; Hofstein & Lunetta 2004; Hsu & Thomas 2002; Raghavan & Glaser 1995; Tao & Gunstone 1999).

Even though there is considerable research in science education on how the use of PM and VM alone enhance conceptual understanding of science (Zacharia, 2007), the scientific literature lacks studies that investigate the impact that different combinations of the two formats of experimentation have on students' conceptual understanding of science (Winn et al., 2006), or studies that compare the impact that these two methods of experimentation have on students' conceptual understanding in science (Finkelstein et al., 2005; Triona & Klahr, 2003; Winn et al., 2006). This study was designed in an attempt to contribute towards this direction. Specifically, it was designed to investigate how the effect of experimenting with VM and PM on students' conceptual understanding in the domain of heat and temperature compared at a specific part of the study's curriculum and whether the effect of experimenting with PM on students' conceptual understanding of heat and temperature changed when PM were complemented with VM.

The selection of the domain of *heat and temperature* for the purposes of this study is justified in terms of its importance as a school science subject and for its pervasiveness in adult life. In addition, several virtual tools exist that provide the learning environment that supports experimentation in this domain (features and interactions of the domain are retained in the virtual world). Lastly, students' conceptions of *heat and temperature* have been extensively studied (Arnold & Millar, 1994; 1996; Brook et al., 1984; Driver et al., 1985; Erickson, 1979; 1980; Erickson & Tiberghein, 1985; Grayson, 1994; 1996b; Harisson et al., 1999; Kesidou & Duit, 1993; Kesidou et al., 1995; Leite et al., 2007; Linn & Songer, 1991; Paik et al., 2007; Rogan, 1988; Rosenquist et al., 1982; Stavy & Berkovitz, 1980; Taber, 2000; Tiberghien, 1980; Wiser & Amin, 2001; Wiser & Carey, 1983). For example, researchers found that the conceptions of heat and temperature are usually poorly differentiated (Brook et al., 1984). Erickson (1977) stated that, the differentiation between heat and temperature is one of the greatest difficulties that students confront. The students tend to believe that temperature is the mixture of hot and cold in an object or just the measure of the quantity of heat of an object, without doing any separation between the measure (temperature) and the quantity of transferred energy (heat) (Driver et al., 1998). Driver et al. (1998) also found that many individuals believe that the temperature of an object relates with its size, its volume or its mass. They consider temperature as a physical property of the material. Their every day experience, in which they touch objects, enforces their conception that specific materials are from their nature hotter or colder than others. These findings along with the findings of other research on students' conceptual understanding in the domain of *heat and temperature* compose an important set of knowledge that could inform the development or selection of effective research intervention materials and strategies. In fact, the *Physics by Inquiry* curriculum was selected because it has been shown, when being implemented through the use of PM and/or VM, to be an effective approach to science learning for undergraduate students (e.g., McDermott, 1992; Redish & Steinberg, 1999; Rosenquist et al., 1982; Thacker et al., 1994; Zacharia, 2007).

METHODOLOGY

Sample

The participants of the study were 62 undergraduate students, enrolled in an introductory physics course that was based upon the *Physics by Inquiry* curriculum (McDermott and The Physics Education Group, 1996), intended for pre-service elementary school teachers. The course took place at a university in Cyprus. The participants were separated into two groups, namely, the Control Group (CG, 34 students) and the Experimental Group (EG, 28 students). None of the participants had taken college physics prior to the study.

In addition, the students in all groups were randomly assigned to subgroups (of three) as suggested by the curriculum of the study (McDermott & The Physics Education Group, 1996). As mentioned before, this particular curriculum is grounded upon a social constructivist framework that provides opportunities for joint decision-making about manipulating events and intellectual transactions about the meaning of resultant phenomena. Partners negotiate what actions to take in the experiment and they also negotiate the meaning of the observed events (Windshitl, 2001).

Curriculum materials: Physics by Inquiry

For the purposes of this study the first three sections of the first part of the module of *Heat and Temperature* were used (McDermott and The Physics Education Group, 1996, p.163). Specifically, the curriculum sections used in this study, focus on constructing an operational definition for temperature (section 1), on investigating temperature changes when samples of hot and cold water are mixed (section 2), and on heat and heat transfer (section 3).

Manipulatives

Physical Manipulatives

The experimentation with PM involved the use of real instruments (thermometers), objects [containers (beakers and Styrofoam cups) and heaters] and materials [solids (wood and aluminum) or liquids (water)] in a conventional physics laboratory.

Virtual Manipulatives

The experimentation with VM involved the use of virtual instruments (thermometers), objects [containers (beakers and Styrofoam cups) and heaters] and materials [solids (wood and aluminum) or liquids (water)] to conduct the study's experiments on a computer. In this study, the Virtual Lab *ThermoLab* (see Figure 1) was used for this purpose [for more details on the *ThermoLab* see Hatziktaniotis et al. (2001); see also Lefkos, Psillos & Hatzikraniotis (2005), Petridou et al. (2005) and Psillos et al. (2000)].

Figure 1. Thermolab

Experimental Design

A pre-post comparison study design was used for the purposes of this study that involved two groups, EG and CG, according to Figure 2. The CG used PM in a conventional physics laboratory throughout the study, whereas, the EG used PM in a conventional physics laboratory for Part A of the study's curriculum (Section 1 of the *Physics by Inquiry* curriculum, McDermott and The Physics Education Group, 1996, p.163) and VM to conduct the study's experiments on a computer for Part B of the curriculum (Sections 2 and 3 of the *Physics by Inquiry* curriculum, McDermott and The Physics Education Group, 1996, p.168).

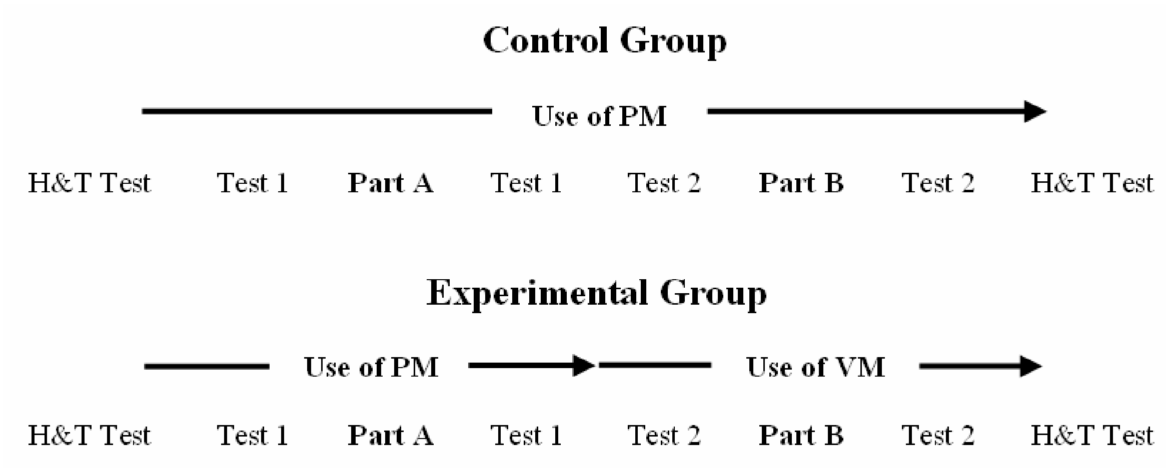

Figure 2. The experimental design of the study

Data Collection

Conceptual tests were administered to assess students' understanding in the concepts of heat and temperature both before and after the study (Heat & Temperature Test or H&T Test), as well as, both before and after introducing each part (A and B) of the study's curriculum (see Figure 2). The tests were developed and used in previous research studies by the Physics Education Group of the University of Washington (e.g., Rosenquist et al., 1982).

Data Analysis

The data analysis involved both quantitative and qualitative methods. The quantitative analysis involved (a) paired-samples t-test for the comparison of the H&T pre-test scores to the H&T post-test scores of each group, (b) ANCOVA for the comparison of the H&T post-test scores of the two groups, and (c) ANCOVA for the comparison of the post-test 2 scores of the two groups, The aim of the first procedure was to investigate whether the use of the combination of PM and VM, and the use of PM alone, within the context of the *Physics by Inquiry* curriculum, improved students' conceptual understanding. The aim of the second procedure was to investigate whether the effect of PM on undergraduate students' conceptual understanding of heat and temperature changed when PM was complemented with VM. The aim of the third procedure was to investigate whether the substitution of VM for PM had a different effect on students' conceptual understanding of Part B of the study's curriculum.

The qualitative data analysis focused on identifying and classifying students' scientific (SAC) and non scientific conceptions (NSAC) concerning *changes in temperature*, *heat* and *heat transfer* (Part B). The analysis followed the procedures of phenomenography (Marton & Booth 1997). In addition, the prevalence for each one of the resulting categories for each test was calculated. The purpose of the latter was to compare if the prevalence of each category of students' conceptions differed prior to and after Part B because of the substitution of VM for PM.

To ensure objective assessment, the tests were coded and scored anonymously. Internal reliability data were also collected. Two independent coders reviewed 25% of the data. All the reliability measures (Cohen's Kappa for the quantitative part and proportion of agreement for the qualitative part) were above 0.87.

RESULTS

The quantitative analysis showed that the combination of PM and VM and PM alone improved students' conceptual understanding after the study ($p<0.001$ for both comparisons). However, the ANCOVA designated that the students of the EG had significantly greater H&T post-test scores than the students of the CG after the study ($p=0.04$). Moreover, a second ANCOVA revealed that the substitution of VM for PM had a significant effect on students' conceptual understanding of Part B. It was found that the EG had significantly higher scores on post-test 2 than the CG ($p<0.001$).

The phenomenographic analysis revealed that the conceptions of EG and CG appeared to be organized in three catecories (see Table 1): (a) heat vs temperature (e.g. measure units, characteristics, intensive-extensive quantities etc.) (b) thermal interaction/changes in temperature and (c) factors causing temperature changes/heat transfer. In addition, the analysis revealed that the two groups shared mostly the same conceptions either scientifically accepted (SAC) or not (NSAC), both before and after the research intervention (see Table 1). However, the prevalence of each conception between the two differed. Between the two groups the EG was found to have, in post-test 2, the highest prevalence for each SAC and the least for each NSAC. This finding indicates that EG appeared to better promote the students' conceptual understanding of *changes in temperature*, *heat* and *heat transfer*, than the CG.

Table 1: Sample of NSAC regarding the understanding of heat and temperature as they emerged from the phenomenographic analysis

Conceptions concerning the understanding of heat and temperature	**Control Group (n= 28)**		**Experimental Group (n=34)**	
	Pre tests % (n)	**Post tests % (n)**	**Pre tests % (n)**	**Post tests % (n)**
Heat vs Temperature				
Heat and temperature are the same entities	7,14% (2)	0% (0)	0% (0)	0% (0)
Thermal interaction				
When two samples of water (of different temperatures) are mixed, temperature from the hot sample is transmitted to the cold one.	64,29% (18)	25% (7)	73,52% (25)	26, 47% (9)
Ice and water cannot coexist at the same temperature	53,57% (15)	3,57% (1)	70,59% (24)	5,88% (2)
Temperature changes (heat transfer)				
When two samples of water of the same temperature are mixed, the temperature of both samples changes according to their mass.	25% (7)	7,14% (2)	14,71% (5)	0% (0)

DISCUSSION AND CONCLUSION

The findings of this study indicate that the use of PM combined with VM or the use of PM or VM alone, when grounded in the framework of the *Physics by Inquiry* curriculum, can provide interactive experiences that enhance students understanding of concepts related to heat and temperature. However, both the quantitative and qualitative analysis showed that experimenting with VM in combination with PM or experimenting with VM alone could promote student conceptual understanding, concerning *changes in temperature*, *heat* and *heat transfer* (Part B), to a greater extent than PM alone. These findings challenge the general assumption that only physical manipulation improves learning. Therefore, the use of VM should not be considered as an excellent substitute of the use of PM, as is usually the case, but as a method of experimentation with great potential, which could be used in combination with PM or even alone, at least within a learning environment similar with the one used in this study.

VM should not, by any means, replace PM or any activity aimed at experiencing and investigating the real phenomena. VM are valued for their flexibility of use, availability for revision and provision of additional information, whereas PM are valued for the hands-on, 3D nature but also for their "reality". However, according to Triona and Klahr (2003), science educators should not be "wedded" to PM "on the basis of folk psychology or vague theory" (p. 171). There is emerging evidence that VM deserves to be given the opportunity to prove itself beyond a series of experiments that might be too expensive, too dangerous or difficult to carry out in real laboratories within specified time constraints (Triona & Klahr, 2003; Zacharia, 2007).

REFERENCES

Arnold, M., & Millar, R. (1994). Children's and lay adults' views about thermal equilibrium. *International Journal of Science Education*, 16, 405-419.

Arnold, M., &. Millar, R. (1996). Exploring the use of analogy in the teaching of heat, temperature and thermal equilibrium. In G. Welford, J. Osborne, & P. Scott (Eds.), *Research in Science Education in Europe*. *Current issues and themes* (pp. 22-35). London: Falmer.

Barab, S.A. et al. (2000). *Journal of Science Education and Technology*, 9, 7-25.

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, D. J. (1998). Doing with understanding: Lessons from research on problem and project-based learning. *The Journal of the Learning Sciences*, 7, 271-311.

Brook, A., Briggs, H., Bell, B. & Driver, R (1984). *Aspects of secondary students' understanding of energy-full report.* Leeds: University of Leeds, Centre for Studies in Science and Mathematic Education.

Bybee R. (2000) Teaching science as inquiry. In *Inquiring into Inquiry Learning and Teaching in Science* (eds J. Minstrel & E.H. Van Zee) , pp. 20– 46. American Association for the Advancement of Science (AAAS), Wasington, DC.

Casey, C. (1996). *The Hill on the Net: Congress Enters the Information Age.* Boston: AP Professional.

de Jong, T. (2004). *Scaffolds for Computer Simulation Based Scientific Discovery Learning.* Enschede, NL: University of Twente.

de Jong, T., & Njoo, M. (1992). Learning and instruction with computer simulation: Learning processes involved. In E. de Corte, M. C. Linn, H. Mandl & L. Verschaffel (Eds.), *Computer-based Learning Environments and Problem Solving* (pp. 411-427). Berlin: Springer-Verlag.

Doerr, H. M. (1997). Experiment, simulation and analysis: An integrated instructional approach to the concept of force. *International Journal of Science Education*, 19, 265-282.

Driver, R., Guesne, E., Tiberghien, A. (1985). *Children's ideas in science*. Milton Keynes, U.K.: Open University Press.

Driver, R., Squires, A., Rushworth, P., Robinson, W. (1998). Η Θέρμανση. *Οικοδομώντας τις έννοιες των Φυσικών Επιστημών – Μια Παγκόσμια Σύνοψη των Ιδεών των Μαθητών.* Αθήνα: Γιώργος Δάρδανος.

Erickson, G.L.(1977). Children' s conceptions of heat and temperature phenomena. Paper presented as part of the symposium on *Patterns of student beliefs- implications for science teaching* at the CCSE convention, June, Fredericton.

Erickson, G. L. (1979). Children's conceptions of heat and temperature. *Science Education*, 63, 221-230.

Erickson, G.L.(1980). Children's viewpoints of heat: A second look. *Science Education*, 64, 323- 336.

Erickson, G. L., & Tiberghien, A. (1985). Heat and temperature. In R. Driver, E. Guesne, & A. Tiberghien (Eds.). *Children' s ideas in science* (pp. 52- 84). Philadelphia: Open university press.

Finkelstein, N. D., Adams, W. K. , Keller, C. J., Kohl, P. B., Perkins, K. K., Podolefsky, N. S., Reid S., & LeMaster, R. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics - Physics Education Research*, 1, 1-8.

Goldberg, F., & Bendall, S. (1995). Making the invisible visible: A teaching/learning environment that builds on a new view of the physics learner. *American Journal of Physics*, 63, 978-991.

Goodyear, P. (1992). The provision of tutorial support for learning with computer-based simulation. In E. de Corte, M. C. Linn, H. Mandl and L. Verschaffel (Eds.), *Computer-Based Learning Environments and Problem Solving* (pp. 391-409). Berlin: Springer-Verlag.

Gorsky, P., & Finegold, M. (1992). Using computer simulations to restructure students' conception of force. *Journal of Computers in Mathematics and Science Teaching*, 11, 163-178.

Grayson, D. J. (1994). Concept substitution: An instructional strategy for promoting conceptual change. *Research in Science Education*, 24, 102–111.

Grayson, D. J. (1996a). Using education research to develop waves courseware. *Computers in Physics*, 10, 30-37.

Grayson, D. J. (1996b). Concept substitution: A strategy for promoting conceptual change. In D.F. Treagust, R. Duit, and B.J. Fraser (Eds.), *Teaching and learning in science and mathematics* (pp. 152–161). New York: Teachers College Press.

Gunstone, R. F. (1991). Reconstructing theory from practical experience. In B. E. Woolnough (Ed.), *Practical science* (pp. 67–77). Milton Keynes: Open University Press.

Gunstone, R. F., & Champagne, A. B. (1990). Promoting conceptual change in the laboratory. In E. Hegarty-Hazel (Ed.), *The student laboratory and the science curriculum* (pp. 159–182). London: Routledge.

Harisson, A. Grayson, D., Treagust, D. (1999). Investigating a grade 11 students evolving conceptions of heat and temperature. *Journal of Research in Science Teaching*, 36, 55- 87.

Hatzikraniotis, E., Lefkos, I., Bisdikian, G., Psillos, D., Refanidis, I., & Vlahanas, J. (2001). An open learning environmentfor thermal phenomena, *Proceedings of the 5th International Conference on Computer Based Learning in Science*, CBLIS, Brno, Chech Republic.

Hewson, W. (1985). Diagnosis and remediation of an alternative concept of velocity using a microcomputer program. *American Journal of Physics*, 53, 1056-1065.

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

Hsu Y. -S., & Thomas R. A. (2002). The impacts of a web-aided instructional simulation on science learning. *International Journal of Science Education*, 24, 955-979.

Huppert, J., & Lazarowitz, R. (2002). Computer simulations in the high school: students' cognitive stages, science process skills and academic achievement in microbiology. *International Journal of Science Education*, 24, 803–821.

Kaput, J. J. (1995). Creating Cyberetic and psychological ramps from the concrete to the abstract: examples from multiplicate structure. In D. N. Perkins, J. L. Schwartz, M. M. West, & M. S. Wiske (Eds.), *Software Goes to Schools: Teaching for Understanding with New Technologies* (pp. 130-154). New York, NY: Oxford University Press.

Kesidou, S., & Duit, R. (1993). Students' conceptions of the second law of thermodynamics – An interpretive study. *Journal of Research in Science Teaching*, 30, 85-106.

Kesidou, S., Duit, R., & Glynn, S. (1995). Conceptual Development in Physics: Students' Understanding of Heat. In S. Glynn, & R. Duit (Eds.), *Learning Science in the Schools*. NJ: LEA.

Kirschner, P. & Huisman, W. (1998). Dry laboratories in science education, computer based practical work. *International Journal of Science Education*, 20, 665-682.

Lea, M., Thacker, B. A., Kim, E., & Miller, K. M. (1996). Computer assisted assessment of student understanding in physics. *Computers in Physics*, 10, 30-37.

Leite, L., Mendoza, J., & Borsese, A. (2007). Teachers' and prospective teachers' explanations of liquid-state phenomena: A comparative study involving three European countries. *Journal of Research in Science Teaching*, 44, 349-374.

Linn, M.C., & Songer, N.B. (1991). Teaching thermodynamics to middle school students: What are appropriate cognitive demands? *Journal of Research in Science Teaching*, 28, 885–918.

Lefkos, I., Psillos, D., Hatzikraniotis, E. (2005). Integrating ICT Tools in a Laboratory Teaching Sequence of Thermal Phenomena. In Z. Zacharia and C. P. Constantinou (Eds.), Integrating New Technologies in Science and Education. *Proceedings of the Seventh International Conference on Computer Based Learning in Science* (pp. 450-460). Žilina, Slovakia: University of Žilina.

Lunetta, V. N. (1998). The school science laboratory: Historical perspectives and centers for contemporary teaching. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education*. Dordrecht: Kluwer.

Mandinach, E., & Cline, H. (1994). *Classroom Dynamics: Implementing a Technology-Based Learning Environment*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Marton F. & Booth S. (1997). *Learning and Awareness*. Maywah, NJ: Lawrence Erlbaum.

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 and the Physics Education Group (1996). *Physics by Inquiry*. Wiley: New York.

National Science Teachers Association (1999). Position statement on the use of computers in science education. Retrieved July 6, 2005 from: http://www.nsta.org/positionstatement&psid=4

Paik, S.-H., Cho, B.-H., & Go, Y.-M. (2007). Korean 4- to 11-year-old student conceptions of heat and temperature. *Journal of Research in Science Teaching*, 44, 284-302.

Petridou, E., Psillos, D., Lefkos, I., Fourlari, S., Hatzikraniotis, E. (2005). Investigating the Use of Simulated Laboratory for Teaching Aspects of Calorimetry to Secondary Education Students. In Z. Zacharia and C. P. Constantinou (Eds.), Integrating New Technologies in Science and Education. *Proceedings of the Seventh International Conference on Computer Based Learning in Science* (pp. 284-295). Žilina, Slovakia: University of Žilina.

Psilos, D., Argirakis, P., Vlahavas, I., Hatzikraniotis, E., Bisdikian, G., Refanidis, I., Lefkos, I., Korobilis, K., Vrakas, D., Galos, L., Petridou, E., & Nicolaides, I. (2000). Complex Simulated Environment for Teaching Heat-Thermodynamics. *Proceedings of the 2nd National Conference with International Participation, The Technology of Information and Communication in Education*, Patra, University of Patra (in Greek).

Raghavan, K. & Glaser, R. (1995). Model-Based Analysis and Reasoning in Science: The MARS Curriculum. *Science Education*, 79, 37-61.

Ravenscroft, A. (2000). Designing argumentation for conceptual development. *Computers & Education*, 34, 241-255.

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

Rogan, J. (1988). Development of a Conceptual Framework of Heat. *Science Education*, 72, 103-113.

Rosenquist, M., Popp, B., & McDermott, L. (1982). Helping Students Overcome Conceptual Difficulties with Heat and Temperature. Paper presented at the meeting of the American Association of Physics Teachers, Ashland.

Shin, N., Jonassen, D. H., & McGee, S. (2003). Predictors of well-structured and ill-structured problem solving in an astronomy simulation. *Journal of Research in Science Teaching*, 40, 6-33.

Stavy, R. & Berkovitz, B. (1980). Cognitive Conflict as a Basis for Teaching Quantitative Aspects of the Concept of Temperature. *Science Education*, 64, 679-692.

Taber, K. S. (2000). Finding the optimum level of simplification: the case of heat and temperature. *Physics Education*, 35(5), 320-325.

Tao, P. & 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.

Thacker, B., Kim, E., Trefz, K. & Lea, S. (1994). Comparing problem solving performance of physics students in inquiry-based and traditional introductory physics courses. *American Journal of Physics*, 62, 627-633.

Tiberghien, A. (1980). Modes and conditions of learning - an example: the learning of some aspects of the concept of heat. In Archenhold, W. F., Driver, R. H., Orton, A. & Wood- Robinson, C. (Eds.), *Cognitive development research in science and mathematics*. Leeds, UK: The University of Leeds.

Triona L., & 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.

Vreman-de Olde, C. & de Jong, T. (2004) Student-generated assignments about electrical circuits in a computer simulation. *International Journal of Science Education*, 26, 859-873.

Windschitl, M. (2001). Using Simulations in the Middle School: Does Assertiveness of Dyad Partners Influence Conceptual Change? *International Journal of Science Education,* 23, 17-32.

Winn, W., Stahr, F., Sarason, C., Fruland, R., Oppenheimer, P., Ling- L.,Y. (2006). Learning Oceanography from a Computer Simulation Compared with Direct Experience at Sea. *Journal of Research in Science Teaching,* 43, 25–42.

Wiser, M. & Amin, T. G. (2001). "Is heat hot?" Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena. In L. Mason (Ed.), Instructional practices for conceptual change in science domains [Special Issue]. *Learning & Instruction*, 11, 331-355.

Wiser, M., & Carey, S. (1983). When heat and temperature were one. In D. Gentner & A.L. Stevens (Eds.), *Mental models* (pp. 99–129). Hillsdale, NJ: Erlbaum.

Zacharia Z. (2003). Beliefs, Attitudes, and Intentions of Science Teachers Regarding the Educational Use of Computer Simulations and Inquiry-based Experiments in Physics. *Journal of Research in Science Teaching*, 40, 792-823.

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.

Zacharia, Z. (2005). The Impact of Interactive Computer Simulations on the Nature and Quality of Postgraduate Science Teachers' Explanations in Physics. *International Journal of Science Education*, 27, 1741-1767.

Zacharia (2007). Comparing and combining real and virtual experimentation: An effort to enhance students' conceptual understanding of electric circuits. *Journal of Computer Assisted Learning*, 23, 120-132.

Giorgos Olympiou
Graduate Student
Learning in Physics Group
Department of Educational Sciences
University of Cyprus
P. O. Box 20537
1678 Nicosia
Cyprus
Email: sep6og1@ucy.ac.cy

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

Marios Papaevripidou
Graduate Student
Learning in Physics Group
Department of Educational Sciences
University of Cyprus
P. O. Box 20537
1678 Nicosia
Cyprus
Email: mpapa@ucy.ac.cy

C. P. Constantinou
Associate Professor
Learning in Physics Group
Department of Educational Sciences
University of Cyprus
P. O. Box 20537
1678 Nicosia
Cyprus
Email: c.p.constantinou@ucy.ac.cy